L. GUTENMACHER • THINKING MACHINES

L. GUTENMACHER

# THINKING MACHINES

FOREIGN LANGUAGES PUBLISHING HOUSE
Moscow

TRANSLATED FROM THE RUSSIAN
BY A. ZDORNYKH

DESIGNED BY V. YERYOMIN

## CONTENTS

# General

## Machines and Mechanisation

Until recently the word *machine* denoted an installation converting one kind of energy into another kind convenient for further utilisation (e.g., steam engines and gas turbines) and also appliances with the help of which the shape, property, state and position of the objects of labour were changed (metal-working, textile, and transport machines). Mechanisation led to the complete or partial replacement of the labour of man and beast by machines. Hence, machine output is measured in units called "horse power".

At first, machines were only capable of replacing directly the physical labour of many people. The invention of various more complicated types of machines and their rapid development resulted in qualitative changes in the form of labour. Machines began to perform complex and difficult physical jobs which, in principle, no man or beast could do. For instance, neither man nor beast by himself is able to develop sufficient power inside an airplane to lift it off the ground. The high speeds required for many complex production processes in various branches of the national economy, which cannot be obtained manually, form another such example.

As science developed and a vast amount of knowledge accumulated, it became necessary to *mechanise mental labour*. Now new types of appliances for performing some of the processes of man's mental activity came under the definition of "machine".

The use of a memory storing information accumulated by a man in the course of his development and intercourse with the outside world is an indispensable condition of

his mental activity. In a broad sense of the word, all the knowledge stored in the memory of a human being can be called *information*. Information is the fuel for the thinking process, and the mental activity of man is based on the processing of this information.

Thinking is attributed only to the human brain. The forms and laws of joining thoughts together into reasoning comprise a special field of science known as *logic*, and in this sense information processing by the human brain may be called *logical*. The processing of information and the deduction of conclusions based upon it consist of the operations of comparison, analysis and synthesis; i.e., they include a number of logical operations on concepts and judgements.

When discussing later on the problems of the mechanisation of some of the processes of mental activity, we shall limit the notion of information to those ideas and notions which can be registered in *writing* (for instance, publications, manuscripts, graphs and tables).

The mechanisation of some of the processes of mental activity means that machines will accumulate, store and process such information in accordance with a logical programme drawn out by man. We shall call these machines *information and logical machines*.

The volume of information accumulated and processed by them should be commensurate with the volume of information processed in the brain of man. This is the first qualitative feature of information and logical machines which sets them apart from other machines.

Just as in any other machine, the information machine processes some kind of raw material which in this case, as we have already said, is the information contained in scientific papers and books. Conventional machines convert raw materials into a finished product. More and more raw materials go into turning out new products.

In information machines there is no waste of raw material and the wealth of information is inexhaustible. This is their second qualitative feature.

Information stored in a machine containing for instance one million words can serve as a foundation for practically any amount of information. Data does not usually become

obsolete. The machine "brain" is gradually enriched with new information, which is either introduced into it from new sources or forms within it as a result of the logical processing of information stored in the machine itself.

Today the production of such machines has become feasible due to the high level of development of radio-electronics. Modern electronic devices make it possible to develop a high-speed machine memory for storing and reproducing a large amount of information as well as high-speed logical elements and units for its processing.

The development of electrically static memory units which do not have moving parts but employ magnetic, capacitative and other elements of the electric circuit was decisive. They can store information for practically unlimited periods of time and reproduce it with very high speed (they can select scores of thousands of information units per second).

Moreover, long-time memory units possess the so-called *address* property, i.e., the required information is retrieved from the memory using its given properties (addresses) directly, without going through the entire content of the memory.

Information and logical machines of the type described above cannot employ such memory devices as magnetic or punched tape, since it takes these devices a lot of time to retrieve information (considerably longer than it takes a man); more than a minute is required to retrieve information from a single reel of magnetic tape. To select required information by means of some given property the machine will have to examine either the entire amount of the stored information (a great number of reels) or part of the reels.

But mechanical motion wears out the tape and damages the information recorded on it. A machine "memory" which is based on mechanical moving parts of any kind does not possess the long-time, safe and hard-wearing qualities of information storage required for the internal memory of the information and logical machines. Therefore magnetic and punched tape, and other types of memory devices based on mechanical motion can be used in the information and logical machines only as information carriers and external

input and output units. In relation to the inner "memory", the external memory will play the same role as a library plays for human memory. It should be mentioned, however, that magnetic discs, drums and tapes were used in the pioneer work preceding the construction of large-capacity internal machine memories.

Thus, long-time, safe and durable storage of information in the machine "memory" is the third qualitative feature of the information and logical machine. The machine must be capable of reproducing the accumulated information without change for years to come.

The processes of mechanised mental activity, naturally, should be related to similar processes of human intellect, just as machine tools and machine motors are to muscle (physical) work.

The operation of information and logical machines is based on mathematical logic and the theory of algorythms* which determine the regularity, conditions and programme for performing this or that mental task.

A man quickly reacts to information expressed in words. It takes him from a fraction of a second to several seconds to retrieve from his memory the required information and all the associations; however, he needs considerably more time to process this information (to compare, analyse and synthesise).

The human brain is immeasurably more capable than any information and logical machine of today and tomorrow as regards flexibility, self-organisation, adaptability to various constantly changing conditions, and a vast range of logical methods. However, if some particular mental task can be expressed with the help of formulas of some sort and an algorythm can be evolved for it, then the machine can retrieve information and process it in accordance with the preset logical operations much faster than this can be done by the human brain. In this case the speed of the machine reaction to the given problem will be com-

* An algorythm or alborism is the programmed automatic work process (a set of routine operations, steps and actions for obtaining the given product of labour) or a given sequence of computer operations for solving a given type of problem.

mensurate with the speed of mental work performed by man, or even surpass it. Hence, this is the fourth qualitative feature of information and logical machines.

## Specialisation and "Qualifiction" of Information and Logical Machines

Information and logical machines can be used, for instance, for the following purposes:

1. To process scientific and engineering data (technological, schematic, diagrammatic; the design of apparatus and machines) by using reports, papers, books, and experimental data as basic raw material.
2. The automation of information searching in world literature. The total printed matter stored in the world amounts to nearly a hundred million publications. Naturally, to search for the required information in this jungle of books is no easy task and man is simply unable in his practical activity to make use of all the material concerning this or that problem without new types of machines to help him.
3. To process the statistical data, which keeps piling up in industry, agriculture, and transport, using as a source all reports, tables, graphs, etc.
4. To process medical data obtained in clinics, hospitals and medical centres. This information can be recorded in the machine memory and logically processed in order to study and prevent epidemics, or to generalise symptoms of various diseases.
5. To process the information data obtained by meteorological and seismic stations, observatories, the Earth's satellites and space automatic stations.

Undoubtedly, human memory is incapable of storing all the data which undergo processing in the above cases. Suffice it to say that there are more than 3,000 meteorological stations today in the U.S.S.R. and each of them conducts 15 kinds of observations eight times a day. The data sent in daily from meteorological stations to the Central Archives amount to several scores of thousands of reports. In order to forecast the weather all this informa-

tion has to be processed along with the data already stored up in the archives. Therefore, it is necessary that the speed of processing is enormous.

The accuracy of stored data reproduction required will permit only machines to tackle this job which practically is beyond the capabilities of a man.

Specialisation of these machines will depend on the functions they perform.

Just as in mechanised physical labour a machine performs some of the functions of a man of a definite speciality (e.g., foundryman, smith, navvy), so an information and logical machine does some of the functions of a mental worker of some definite speciality (e.g., bibliographer, scientific worker, engineer, doctor or planner).

Just as mental and physical workers receive their qualifications, the machines can also be "qualified" by the quality of the finished product and by the number of operations they perform. Since the amount of information stored by the human brain and the character of *logical links* are decisive in mental work, the "qualification" and "capacity" of an information and logical machine should be evaluated by the amount of information stored in the machine's "memory", by its logical capabilities (the complexity of its operation programme), and by the information access time.

The information and logical machine "qualification" depends not only on the amount and quality of information stored in it, but also on the quantity and quality of its programmes.

The programme drawn up by an operator defines the sequence of logical operations in data processing. The machine obeys this programme automatically and can switch from one programme over to another. Moreover, the machine is capable of drawing up automatically new programmes from those already stored in it for solving new problems (its capacity for programming programmes).

Before recording in the machine "memory", the material is first reduced to a convenient recording form. For instance, any arbitrary grammatical form of a sentence from a book which comprises the initial information may be reduced to a standard form of recording by definite rules

(making standard sentences). Words and signs of the text are translated—encoded—into certain standard symbols. Other kinds of initial information undergo similar encoding.

The operation programme is encoded in a similar way. A code is a sequence of symbols or a series of combinations made up of different elements which can be represented by figures in a system of computation or by letters of the alphabet. For example, in the binary system numbers are recorded with the aid of only two figures, namely 1 and 0. This system is most convenient for recording and processing information in electrical systems, since the elements of the code represent one of the two possible steady states ("yes"—"no", "on"—"off"). *Therefore, the volume of information stored in a machine is usually estimated from the number of recorded binary signs.*

The machine memory units are characterised by the number of cells (addresses) in them and by the number of bits stored in each cell. For example, in a memory of a hundred thousand addresses (cells) 50 bits in each address correspond to a total memory of 5 million bits.

The speed of operation of an information and logical machine is determined primarily by the speed with which the machine selects the needed information from its "internal memory" and compares this information against the given data.

The retrieval speed depends largely on the arrangement of the machine memory address system. In conventional electronic computers, a *numerical* address system makes it possible to select information only by the given number of the memory cell, while in information and logical machines information is retrieved not only by the given number, but also directly by the given word (*word* address system) or by some given association (combination) of notions, making up an *associative* address system.

A perfected machine memory is the fifth specific feature of information and logical machines.

The execution speed of logical and arithmetical operations in the machine is also of vital importance.

The information and logical machine receives questions and information from its external units and sends to them answers and solutions of the problems.

Information is fed into the machine in various ways:

1) direct "reading", with the aid of an image translator (the machine's "vision");

2) with the aid of punched cards and tapes, magnetic tapes, discs or drums (the machine's "sense of touch");

3) with the aid of devices converting speech audio oscillations into electrical signals which are then recorded (the machine's "hearing").

The "final product" of the information and logical machine should be expressed in writing so that it could be used either by man or by other machines. Therefore, the results of the machine's work should be brought out via special (output) devices.

Information at the machine output can be obtained either in the form of printed references, tables, documents, or reproduced on the screen of a cathode-ray tube or through loudspeakers (speech).

## Block Diagram of an Electronic Information and Logical Machine

The principle of operation of the information and logical machine is illustrated by the following block diagram (Fig. 1).

The information is fed into the machine via input and encoding units from various external information sources: a typewriter keyboard, punched cards, perforated tapes or microcards, magnetic tapes, image translators which directly "read" printed texts from the books, magazines, films and microcards.

In the coding unit information is converted into a binary code, and then is recorded in the long-time memory system as electrical signals with the help of a recording and checking system.

The long-time memory system comprises a number of units ("books") in which all the information introduced into the machine is stored. These units are combined into a common address system of information retrieval and constitute the machine's long-time "memory" or its "library".

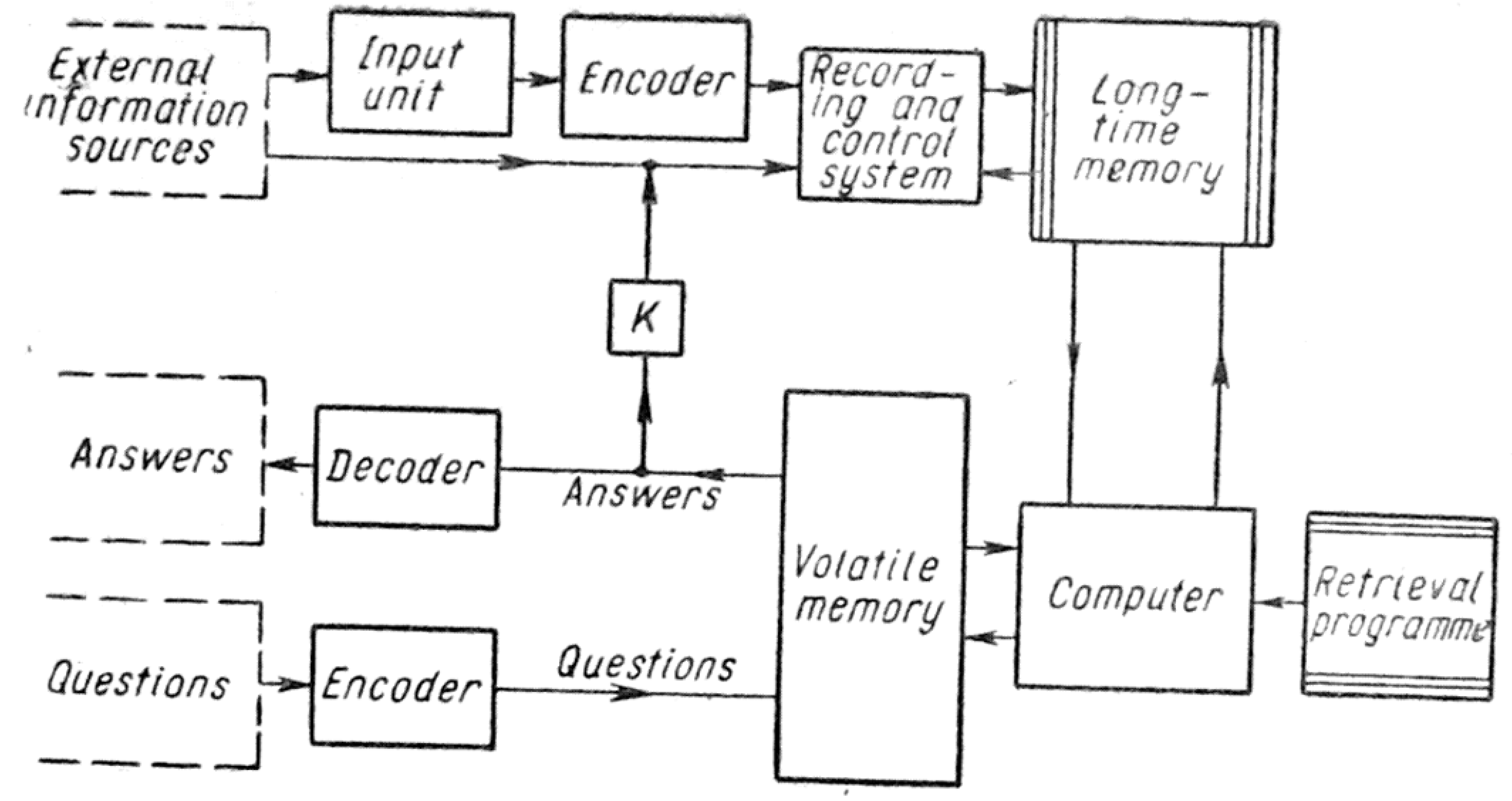



*Fig. 1.* Block diagram of an electronic information and logical machine

Outdated or useless information can be easily extracted from the library and replaced by fresh information by cutting off automatically some of the "pages" in the books and connecting new ones instead.

The machine memory can be gradually enlarged. The more initial data are stored in the machine, the more valuable it becomes. The machine's answers which are specially valuable can be introduced into its long-time memory via the special internal coupling *K* as new information worked out by the machine itself.

Encoded questions with the programmes indicated for retrieving the answers arrive at the volatile memory unit in which all volatile information (questions, intermediate results of the logical information processing, answers) is electrically recorded and stored temporarily. The volatile information is stored only as long as the immediate problem is being solved and is then erased electrically. After that the volatile memory is ready to receive fresh information.

Standard retrieval programmes are recorded in certain units of the long-time "memory", which are not part of the main library and are connected to the machine's computer. Retrieval programmes can be added to the programme storage, thus expanding the scope of problems that can be tackled by the machine.

The use of a high-speed, long-time memory for storing operation programmes gradually raises the "qualification" of the machine and makes it more flexible and adaptable to changes in the range of problems. This is an essential qualitative feature of machines with long-time memory.

A computer is also coupled with a long-time and volatile machine memory. It comprises information reproduction units, comparison, logical and arithmetical units.

The answers to the questions and problems fed into the machine accumulate in the volatile memory and then are converted in the decoding unit into conventional printed text and produced at the output unit as reference data.

## Machine and Human Memory

Before developing and constructing information and logical machines we must analyse the processes connected with the corresponding mental activity of a human being.

What do we know of the work of the human brain?

As early as the 5th century B.C., Hippocrates, the Greek physician, initiated the scientific method of studying the human brain. He wrote that it is the brain alone that gives rise to our feelings of joy or sorrow, that it is only thanks to our brain that we are able to see and hear, and can distinguish between ugly and beautiful.

The human brain is the organ of higher nervous activity. Its core is the accumulation of microscopic cells called neurones (grey matter). They number somewhere between 10 and 15 thousand million. The neurone cell body is approximately 1 mm long, and its base is 0.01 $mm^2$. Neurones are interconnected with the help of "wires" called neurites and dendrites. The volume of a brain is approximately 1.5 $dm^3$, the weight is approximately 1.2 kg and its power about 2.5 Watts.

Research showed (by means of electroencephalograms) that the activity of neurones is a form of electrical activity incorporating changes in electric potential. The neurone potential measured from the outer shell is approximately 0.1 V.

Each sector of the cerebrum performs a definite mental function, i.e., the functions of separate sectors are strictly

localised. However, along with this assumption there are hypotheses which deny such strict localisation.

The results of the following experiment speak in favour of the assumption that separate parts of the cerebrum are localised:* during operation on the cerebrum under local anaesthesia, a certain sector of the right-hand part of the core was excited by electric current through an electrode. The patient said that he heard music. Each time the electrode was placed at this spot or near it the patient heard orchestra music. She was asked to reproduce the tune but she was unable to do that without the spot being irritated by the electric current.

Another patient recalled a certain book she had read, when a definite part of her cerebrum was irritated. When the current was applied a mere centimetre from the spot she began to laugh—a funny story came to her mind.

The conclusion can be drawn from this that everything a man experiences actually is recorded in his brain.

Emotions which a man experiences when certain spots of his brain are irritated are not simply recollections. They are rich in details which cannot be recalled even when we exert our memory, and are so vivid that the patients were either startled or could not restrain their laughter, although they clearly realised that they were being operated upon.

However, there is much in the psychological life of a man that can never be induced as a response to an electric pulse. Creative thought, purposefulness, acts of volition cannot be induced as a psychological answer to the irritation of some spot of the cerebrum.

The cerebrum is linked up with the outer world and with its own organism via subcortex centres through which impulses arrive from the sense organs. Excitations in the cortex consequently pass from one layer to another (there are six layers altogether) and from one spot to another, some parts of the core being, all the while, in a state of excitement and others in a state of inhibition.

In the process of mental activity a mosaic of excited and inhibited centres (groups of neurones) is formed and changes dynamically, as in a kaleidoscope.

---

* Penfield. *Proceedings of the National Academy of Science*, V. 44, No. 2, 1958.

A neurone can be excited approximately 200 times per second. The excitation level of many neurones (the intensity) is approximately from 6 to 60 pulses per second, the excitation being transferred via a frequency-pulse method at an average rate of about 10 exciting periods per second.

*Reproduction*, i.e., conscious reflection in our brain of a number of objects, takes place consecutively in time, approximately with the speed that one utters mentally a word which expresses some object of thought. If we take this speed to be equal to about 0.1-1 sec, the speed of thought is not so very great. This phenomenon of the consecutive mental reflection of the objects is called in psychology the limit of consciousness.

*Memorisation (impression), reproduction and recognition are all processes taking place in our memory.*

*Memorisation* is the process of formation of firm bonds in the human brain which can be easily reproduced later on. Since the objects and phenomena of the outside world are interconnected, they are memorised not in isolation but in combinations, groups or *associations*.

The real bonds of objects of the outside world are expressed by conditional, temporary bonds. There are various types of associations in the cortex.

1) *Associations by contiguity* (in space and time) arise when reproduction of this or that phenomenon or object in our memory is accompanied by recollections of other phenomena or objects connected with the given one in space and time.

2) *Associations by resemblance* arise when recollection of this or that object or phenomenon brings to mind the memory of similar objects and phenomena.

3) *Associations by contrast* arise in recollections of sharply contrasting objects or phenomena (day—night, black — white).

*Reproduction* of phenomena, objects, thoughts, feelings, etc., is the result of activisation of earlier temporary bonds. If man did not store past experience in his memory and was deprived of the ability to reproduce it he would be unable to recognise objects or think about them; he would lose his orientation in the world.

*Recognition* is the process of restoration of temporary bonds as a result of the repeated action of the external irritant.

In the course of million years of its development humanity has created speech and languages. With the help of a certain consequent (one-dimensional) chain of words a man can bring up in his as well as in other people's memories complex images which can be shifted in time and space. He transforms the results of his thoughts (in time-and-space images) into one-dimensional chains of word-symbols with the help of some complex brain converters. How these converters are designed is one of the greatest secrets of the nature of the structure and functioning of the human brain.

It is interesting to calculate the volume of written information that human memory can receive from outside, taking into account its "narrowness of consciousness". Determine, for example, the number of words a man can read if he apprehends printed information with the speed of three words per second, reading 12 hours a day for 50 years running. The calculation would show that under these conditions, a man can read 24,000 books of 300 pages each. This corresponds to 2,400 million words or 84,000 million bits: 3 words $\times 3{,}600$ sec $\times 12$ hours $\times 365$ days $\times 50$ years $= 2.4 \times 10^9 = 2{,}400$ million words.

If we take each word as consisting on an average of seven letters each and each letter is expressed by five binary signs of the telegraph code we will get $2.4 \times 10^9$ words $\times 7$ letters $\times 5$ signs $= 84{,}000$ million binary signs.

The average volume of one book is 300 pages with 350 words to a page:

$$\frac{2.4 \times 10^9 \text{ words}}{350 \text{ words} \times 300 \text{ pages}} = 2.4 \times 10^4 = 24{,}000 \text{ books.}$$

The volume of information calculated here is many times overestimated, since a man is unable to comprehend for long period on end. Brain cells are overcome by fatigue and a protective inhibition sets in.

It should be noted that the neurones of the cerebrum participate to a considerable degree in the processes con-

nected with the first signal system of activity which we did not take into consideration here.

Of the multitude of irritants which participate in the mental process we discuss only the action of irritants in the form of words and combinations of words, i.e., the action of the second signal system of reality.

However, the above calculations give us some idea of the possible volume of information which should be introduced into the memory of the information and logical machine (many thousands of millions of bits).

When we designate objects of perception by words, the result is that not only bonds between the images of these objects are formed in the human brain but also bonds between words corresponding to these objects. We need words to memorise definite objects as well as to exchange experience, to think consciously.

Ivan Pavlov said that "with word, a new principle of higher nervous activity was introduced—the abstracting and generalisation of countless signals . . . with the analysis and synthesis of these new generalised signals, a principle was evolved, which allows the unlimited orientation of man in the surrounding world and creates his higher adaptation—science. . . . "*

The second signal system is the bearer of *abstract thinking*.

V. I. Lenin in his "Philosophical Notebooks" wrote that any word (speech) already generalises. "Imagination cannot grasp movement as a whole, for instance, it cannot grasp movement at a speed of 300,000 km per sec., while thinking can and must."

The process of thinking activity consists in solving a problem whose answer is not given directly but is found as a result of a number of logical operations on the basis of information stored in the memory. Any problem is solved on the basis of the temporary bonds formed as a result of previous experience.

I. M. Sechenov wrote: "Not a single thought passes through a man's memory in his lifetime, which is not made up of elements registered in his memory."

---

* I. P. Pavlov. *Works*, Russ. ed., Vol. 3, Book 2, Academy of Sciences of the U.S.S.R., 1951, p. 215.

The reaction of the machine to various practical questions can be compared with the answers of experienced workers in the appropriate fields. Thus practice can serve as a criterion of the correct operation of the machine.

We should build information and logical machines which would perform functions corresponding to those of mental workers (reference, advisory, research and other functions) at such a speed of reaction and with such intelligence that the dialogue between a man and a machine was conducted in the time scale of a usual dialogue (i.e., a dialogue between two people). Introducing a great number of questions and obtaining answers to them some time later, a time much longer than the time necessary for a man to answer the given questions, would be the easiest and simplest condition for the machine operation. However, an ideal would be the execution of the given mental work in conversational tempo when the speed of the machine's reaction to the posed question matches the speed of the brain's activity or even surpasses it.

In this case the machine might contain all the information accumulated by humanity on the given question in printed form, i.e., it would possess maximum erudition.

Psychology deals with the human intellect while it reflects the objective world, while neuropsychology deals with psychological processes which take place in the course of thinking. Although much success was achieved in studying human mental activity, scientists are unable as yet to interconnect a number of psychological processes in the cortex with psychological phenomena. At present we do not possess sufficient data to understand how information is processed in the human brain. We can only establish a certain similarity between functions performed by machine memory and human memory. Naturally, machine memory does not require the same biophysical and biochemical processes that take place in the cortex. In designing information and logical machines it is expedient to model certain processes of mental activity making fullest use of the achievements in the field of neurophysiology and psychology which have shed light on some aspects of the activity of the human brain.

The first power machines directly copied the mechanism of physical labour of a definite type. Later on this imitation could not satisfy the growing requirement of complex and powerful machines to perform the work of people of many specialities. Such implements of labour appeared as, for example, the wheel, which has nothing to relate it directly to the processes of muscle effort in human beings or in animals; also flying machines were created, the principle of operation of which is quite different from the laws governing the flight of birds. A result was no longer attained by mechanical imitation of the process under investigation but rather by the resultant action, the final solution of a problem, irrespective of the methods by which this problem could be solved.

Methods of artificial modelling of physical processes based on similarity resulted in the solution of many important practical problems.

The method of electrical modelling—the method of electroanalogy—is probably the most far-sighted and useful for studying certain processes of human mental activity.

## Machine Problems

Information machines use the results of the cognition of the surrounding world by humans. In written language people have recorded in sufficient detail, with numerous repetitions and in many variants, gradually introducing clarity of concept, everything they have managed to know by exerting influence on the material reality in their practical activity. People's feelings reflecting various properties of objects and phenomena (colour, smell, sound, etc.) acting upon their organs of senses were described in the fullest detail.

The results of the processes of human thinking, i.e., the results of the generalised cognition of reality connected with the formation of conceptions, with the singling out of essential traits and characteristics of objects, as well as with judgements of these or those facts, suppositions and conclusions arrived at by logical deductions, have also found their description.

Written language helps us to analyse changes, the dynamics of the development of conceptions, judgements and conclusions.

Continuous development of the methods of production, the achievements of up-to-date technology, new scientific generalisations and discoveries, and the unravelling of mysteries of nature go to enrich human thought with new concepts, judgements and conclusions. "To really know a subject," wrote V. I. Lenin, "we must embrace, study all its aspects, all its bonds and its influence upon us. We will never achieve it in full, but the requirement of thoroughness will serve as a warning against mistakes, against putrefaction."*

Conceptions of time and space, of various forms of energy, conceptions of atoms and molecules undergo radical changes. Practical work reshapes nature and social life, organises the process of cognition, changes our concepts, and allows us to evaluate what is true and discard what is false. "...Things exist outside us. Our perceptions and ideas are their images. Verification of these images, differentiation between true and false images, is given by practice."** "Knowledge is the reflection of nature by man. But this is not a simple, not an immediate, not a complete reflection, but the process of a series of abstractions, the formation and development of concepts, laws...."***

Since the operation of the information and logical machines would be based on the gradual absorption by their memory of all printed matter containing facts and phenomena, generalisations and comparisons, criticism and the results of verification, these machines will help us to speed up the process of further specification of our concepts, and the formation of abstractions and deductions, taking full account of practice as the correct criterion.

In connection with the dialectic development of our ideas and concepts we might use the machines in the future for compiling dictionaries of conceptions, definitions and associations on the basis of present-day literature. When

---

* V. I. Lenin. *Works*, Russ. ed., Vol. 32, pp. 71-72.
** V. I. Lenin. *Collected Works*, Vol. 14, FLPH, p. 110.
*** V. I. Lenin. *Collected Works*, Vol. 38, FLPH, p. 182.

analysing such an encyclopaedia of notions, we would find contradictions and propositions that have become obsolete, and we would reveal new and progressive ones. We would be able to analyse the processes of the change and formation of the given notions.

The practical application of the machines with large-capacity memory will suggest new ways of the development of cognition through the utilisation of the collective human intelligence reflected in this memory.

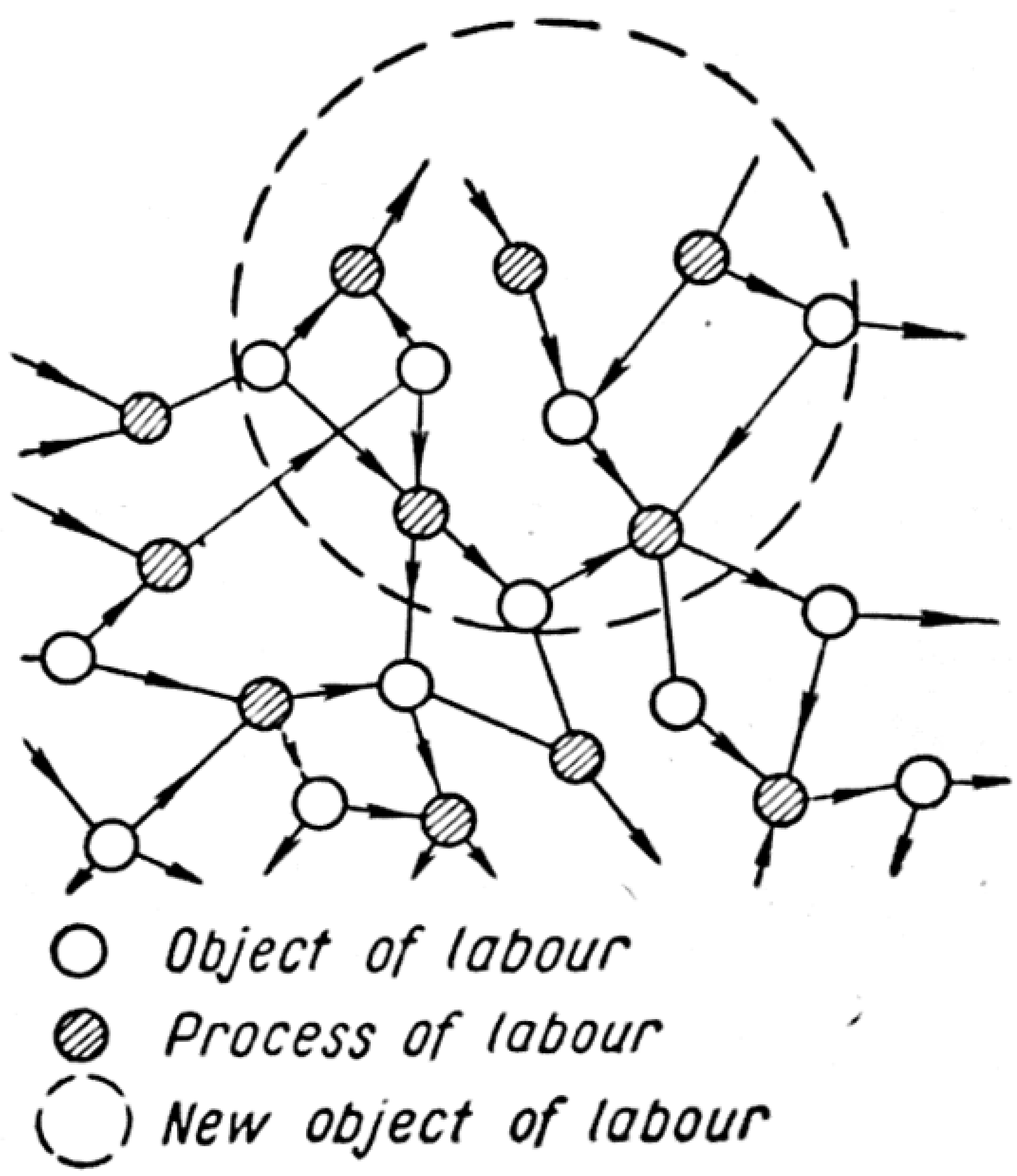



*Fig. 2.* Illustration of the scientific information processing

Let us discuss, for example, one of the problems of scientific and technical information concerning processes and objects of labour. Schematically this problem can be depicted as follows. We shall denote each object of labour by a circle (Fig. 2) and give it a certain number, say 0798, 3721, 0011, 1792, etc. Each process of labour will be represented by a shaded circle.

In the process of labour a new object is created from one or many initial objects of labour which in their turn were obtained in the same way. Linking objects and processes of labour in this way, we will obtain an intricate network with objects and processes of labour in key points (circles in Fig.2). Arrows indicate the direction of processing.

Any industrial production can be reduced to a similar scheme. Every object of labour (e.g., lathe, condenser, plastic, brick, pig iron) has its own description, its definite properties, basic specifications, parameters, utilisation, "place of birth", history of development, etc.

All processes of labour are characterised first of all by the initial raw material and by the final result, i.e., by the objects of labour which participate in the processing of one object into another and by the conditions ensuring

the required course of the processing (e.g., temperature, pressure, medium). These processes of labour are also described in articles, books, technological charts, instructions, etc.

The effectiveness of the process, the history of its development and dynamics, its utilisation and other data can be obtained from books and scientific papers.

Information about objects and processes of labour cannot be systematised once and for all. Their names and even the very content of their conceptions change with time. This process continues sometimes in an evolutionary manner, sometimes by leaps and bounds.

Thus information on the processes and objects of labour changes dynamically every year, every month and even every day. Some of the processes and objects of labour die off and new bonds appear, which also change. For instance, in the 'thirties a new material came into being—synthetic rubber—produced from potatoes and other farm products. Today we have many new kinds of synthetic rubber with quite different processes of production derived from the by-products of the oil and gas industry.

Thus the circle "rubber" in Fig. 2 first went through a certain change and was divided into natural and artificial parts. The bonds also changed. Gradually this circle has acquired in the general diagram such a significance that alone, should we formulate its new content and new bonds, it can be represented by an extensive network comprising raw materials and final products and also numerous processes which make up the general process of manufacturing synthetic rubber.

This example goes to show that every object of labour and process of labour can in turn be represented by a network similar to the one shown in Fig. 2. In some cases it is necessary to enlarge the scale in one part of the network and in other cases to reduce it. This means that part of the given network can be included in one circle without changing the bonds, and one or several circles can be replaced by networks.

The scale is either enlarged or reduced depending on the problem to be solved. If detailed information on the process is sought then the content of the circle should be

determined and replaced by the corresponding network; on the other hand if the material under study refers to a series of processes, certain circle cells are then replaced by separate circles.

The present system of systematic subject indexes used in libraries, scientific papers and patent bureaus can be accepted as the initial system of distribution of information by objects and processes of labour. The contents of scientific papers, handbooks, textbooks and patents will serve as the basic material for the first information machines.

Since the machine method of selecting the material with analysis and synthesis in accordance with the preset programme introduces a new qualitative aspect in this process of mental activity, the question on the classification of information will be treated accordingly.

Just as an increase in the speed and in the specific power of engines per unit of weight led to a new qualitative leap in the field of transportation—flight became possible (a change resulted from movement in a plane to movement in space), the greater accuracy and speed of information examining and processing should in principle lead to new methods of selecting scientific and technical information and consequently to new systems of data classification.

The popular saying that "labour made man" can be conditionally referred to information and logical machines. The use of machine labour for obtaining answers to given problems can improve and harmonically develop these man-controlled machines, which are capable of performing some of the processes of mental activity.

Existing scientific and technical information can be processed and adapted for the machine memory only with the help of machines. Therefore the primary task in this direction is the development of algorythms (processing rules) which will allow the recording of information in the long-time memory of the machines by simple machine methods. At first these processes will develop in certain fields of science and industry (for instance, chemistry, physics, metallurgy, electronics).

Special algorythms will in their turn be created for obtaining the answers to the problems. One of them will

help to find the products of labour under preset properties or find processes of labour under the most favourable conditions. Since one and the same product of labour can be obtained by various processes (say, by the casting or welding of parts) the machine's set of operations must include the following logical actions: and—and; or—or; if—then; no.

Certain retrieval programmes should make it possible to select objects of labour consisting of combinations of parts.

It is known that a new object can be most rationally developed by new specifications from already existing parts that have been tested in operation of other objects—the products of production. The solution of this problem will entail the deciphering of the content of those "circles" in the common diagram we have spoken about, through synthesis of the new and old and the establishment of similarities between the processes.

## Machine Tests

It would be correct to try to model certain mental processes by studying the possibilities of solving simple tests with the machine. Intelligence tests are used, for example, in Britain when selecting eleven-year-old children for various schools.

Although this method is insufficient and not perfect, nevertheless it is expedient to make use of it considering that the solution of this or that test problem is closely linked up with certain typical elementary mental processes.

Reproduction of the processes of solving problems given at schools will be our next step in modelling.

There were frequent attempts to evaluate quantitatively intelligence and knowledge. The famous inventor Thomas Alva Edison worked hard for a long time trying to think up a test that would help him to select objectively his successor.

Although the problem of quantitative evaluation of intelligence is far from being solved, we must make broad use of the expe ience accumulated in this field in developing information and logic machines. Let us then examine some of the examples.

**Test 1.**

1) In five minutes recall all the words known to you which start with syllables: pro, en, rev, mod, con, in, men, re;

2) same with the words ending in n;

3) same, but each word should contain eight letters.

For this test the machine should have an automatic dictionary with letter (alphabetic) address system. When preset syllables are fed into the system, complete words recorded in the machine memory should appear at its output. According to the second stipulation of the test the machine should select words ending in n, and eight-letter words according to the third stipulation.

A dictionary of 15,000 words averaging eight letters a word in telegraph code (five binary signs per letter) will require 600,000 binary signs.

The speed with which the answer can be obtained depends on the type of memory unit. It can be reproduced on a cathode-ray tube screen (of the television type) or may be printed on paper. The machine will tackle this test with ease. Comparison with man will be to the machine's advantage since the test reveals the inaccuracy and unreliability of human memory.

Another stipulation of the test is to compile words from two separate parts. For example we feed into the machine the following syllables: re, me, pre, mo, com, ry and order it to put them together into words. The machine should compare various combinations of these syllables with the words stored up in its memory, for instance: remepre, mepremo, memocom, memory. Obviously only the combination "memory" has a meaning and therefore will be retrieved from the dictionary. Man solves the test in very much the same way.

Now let us present the task in a different way. Can a machine draw up such texts automatically, issue them to a person subjected to such a test, check his answers and make conclusions on the results of the test? Undoubtedly! To introduce random elements in the selection of examples the machine should have a signal source reproducing codes of random numbers just as is done in a lottery. The automatic process will then be as follows: The source or the

so-called *random number transmitter* at first selects a certain number of words from the automatic dictionary. They are then transferred to the volatile memory to be reproduced in parts for the person taking the test either on the screen or in print. His answers will be compared with the full words recorded in the memory. The counter will calculate the results of all the tests.

Test 2. Selecting synonyms.

Select from the given number of words two words which denote one and the same thing or practically one and the same thing, i.e., which are synonyms.

1) *attempt, daring, timidity, lucidity, shameless, bold*;

2) *enormous, fat, tall, courageous, big, heavy*.

To carry out this test the machine memory should be supplied with a vocabulary of synonyms. The process of retrieval in this case will be rather complicated, since the addresses of each association of synonyms cannot reflect all the words they contain. Therefore, the process of retrieval will consist of two operations. First, the address of the associated words should be found using the given word, and then the words of the given series should be searched for the purpose of comparison.

Thus in the given example, by the word *attempt* the machine should find the address of the words associated with this particular word and then compare them with the words *daring, timidity*, etc. The answer in this case will be negative. Searching further the machine will find that the words *daring* and *bold* are synonyms.

A vocabulary of synonyms is also desirable in the machine to cut down the number of form-words used in the machine memory for recording scientific and technical information.

Machine language does not require rich, literary language with a great number of synonyms. It should be as simple as possible so that the thoughts expressed have only one meaning and so that complex sentences can be converted into standard simple ones.

It is interesting to note, however, that the machine can "enrich" the phrases of its answers with the help of the automatic machine dictionary of synonyms by replacing typical words of the machine language by their synonyms.

As a curiosity it may be mentioned that the vocabulary of synonyms can be used for selecting rhymed words by the preset meaning.

Test 3. Finding a word with the opposite meaning:

1) from the word *hot* out of the words: *wet*, *comfortable*, *cool*, *wintry*, *cold*;

2) from the word *inquisitive* out of the words: *disinterested*, *impatient*, *forgetful*, *erudite*, *preoccupied*, *strange*.

For the machine to carry out this test its dictionary of synonyms should be enlarged with antonyms—words with opposite meaning—arranged in corresponding pairs of antonym associations.

Test 4. Classification.

Find words alien to the given semantic group of words: *axe*, *chisel*, *saw*, *hammer*, *bullet*. To cope with this test the machine needs a dictionary of definitions or an explanatory dictionary. All the given words, except the word *bullet* will have one common purpose; they all denote woodworking tools.

A word whose meaning is defined and used in scientific language is called a *term*. Each field of science has its own dictionaries of terminology.

Explanatory dictionaries of household words and colloquial expressions have appeared compiled, for example, in Russia by V. Dal and D. Ushakov and in the United States by Webster.

At present there exists a considerable number of various types of dictionaries for a wide range of practical use.

To classify words we must find what they refer to and then carry out the logical operations of comparison and exclusion.

A diagram and a programme of operation of an automatic unit can be developed for drawing up such tests based on the already existing systems of classification and dictionaries.

Test 5. Finding analogy.

Find an analogy using the given relation of two words:

1) *fire* is related to *warmth* just as *lamp* is to . . . (select the necessary word from the following group of words: *flame*, *candle*, *see*, *light*, *accurate*, *soot*);

2) *sail* is related to *boat* just as *engine* is related to . . . *wind*, *steam*, *ship*, *automobile*;

3) *telephone* is related to *ear* just as *cinema* is related to . . . *picture*, *look*, *eye*, *hear*.

To carry out this test the machine should analyse certain associations and notions containing the required information.

Analogy may be defined as the conclusion which is drawn from the comparison of the characteristic features of two objects (class, group). The conclusion is drawn based on the comparison of the characteristic features of one object with a number of features characteristic of the given group of objects, that this object is similar to the objects of the given group. Analogous conclusions are conclusions in *probability*. For instance, Franklin concluded that the nature of lightning is analogous to the nature of the discharge spark in the Leiden jar (a capacitor).

It is, of course, impossible to draw up once and for all a complete list of characteristic features of comparable objects. These features are gradually revealed and further defined. You will come across their description in various sources. Therefore to find an analogous word with the help of a machine is quite a formidable task requiring special programming. The tests given below illustrate the retrieval steps.

**Test 6.**

Given:

1) Leonid is taller than Pyotr, Ivan is shorter than Leonid. Who is the tallest—Leonid, Pyotr or Ivan?

2) Five people, *A*, *B*, *C*, *D*, *E* sit side by side on a bench. *A* is sitting with *C* on his left, while on his right sits *E*. *B* is sitting between *D* and *E*. The question is who is sitting on the extreme right?

This test requires a programme of simple operations. The point of interest is of course how the machine draws up its own programme. Here lies the crux of the problem. For the words Leonid, Pyotr, Ivan or designations of five people *A*, *B*, *C*, *D*, *E* are substituted symbols of machine language, and for the words taller, shorter, on the right, on the left, between, special symbols are needed.

In this test the machine produces premises and a few conclusions. To pick out the correct conclusion is already the task of the logical machine the description of which will be given below.

The problem of drawing up such tests is far less complicated. A great number of examples for making logical conclusions chain-connected with each other should be inserted into the machine memory. The random number transmitter and a problem selecting programme will be of help in arranging various tests.

**Test 7.** Selecting words in a sentence (synthesis).

The problem is to select the word omitted in a sentence so that the latter acquired meaning.

1) A locomotive runs along . . . .

2) Concrete is . . . . material.

3) Electric . . . . is used in industry.

To perform this test the so-called dictionary of definitions which includes, in particular, the words sought for: rails, building, current can be used. This dictionary will be 20 to 30 times bigger in volume than the number of words in the given language depending on the scope of coverage of various fields of knowledge. Each defined word is supplied with information from 20 to 30 words. This is how explanatory terminological dictionaries and dictionaries for translation from foreign languages are usually compiled.

The volume of machine memory containing 15,000 words will be equal approximately to 15,000,000 binary signs. A machine with such a memory can solve the given tests comparatively rapidly.

However, in these tests words may have different grammatical forms (number and case of a noun or pronoun, person, number, tense and mood of a verb, etc.).

When compiling a dictionary of all possible forms of the words used, the difficulty can be eliminated by inserting into the machine a supplementary automatic dictionary containing full forms of the words or just word stems plus a table of endings.

This problem is similar to those which have already been solved in machine translation from one language

into another and in converting conventional text into information language.

Omitted words, necessary to make up sentences, can be sought not only with the help of terminological dictionaries but also by using the entire store of information contained in the machine. Naturally the time required to solve the problem will increase considerably.

The analysis of the problems under discussion shows that in principle they all can be carried out by information and logical machines equipped with automatic dictionaries, associative memories and logical units.

It is important that by analysing publications (books, articles, reports) these machines could supplement and enlarge such dictionaries in accordance with specified programmes. It should be noted that the machine memory and logical computers make it possible to develop *training stands* for training people's memory and checking the speed of its reaction to verbal questions. This field of application of information and logical machines is just beginning to be developed and, most probably, will be of considerable practical importance in the future.

# Machine Memory

## External Memory

If a method were found for artificial reproduction of information acquired by people in the course of their lives from the gray matter of our brains, it would be one of the greatest scientific discoveries ever. Today we know for certain that even if our brains stop to function temporarily our memory will persist.

At the dawn of the development of human society experience was passed on orally from father to son, from mother to daughter. The need arose to work out a system of external memory supplementing our brain memory and devoid of its shortcomings—its distortions, inaccuracies and short life. Developing trade, military negotiations and treaties, legacy procedures, for example, required the exact recording and transmission of thought over distances.

Several millenniums have passed since the time when people (who have lived on the Earth for nearly one million years) learned to record their thoughts for the first time with the help of characters written on cave walls, on clay plates, then on papyrus, parchment and later on paper (invented in China in I-II century A.D.). For centuries books were written by hand. The number of books grew rapidly but the number of copies lagged far behind, since it took a lot of time to make several copies of one book. In 1441 Johannes Gutenberg invented the printing press and book editions soared. Before the 15th century the number of books was so insignificant that a man was unable to get acquainted with all the literature simply because there were not enough books. From the beginning of the 20th century book editions grew to enormous proportions. At

present the amount of printed matter is so great that man is unable to read in his lifetime even the tiniest portion of literature printed all over the world.

The works of literature created by humanity have enormous cultural value. However, readers make an extremely insufficient use of all the books and magazines collected in libraries. Thus, for example, more than half of the books and magazines collected at the Lenin library have never been requested as yet. This can be explained by the fact that the gap between the limited capabilities of man and the enormous pace at which our literature develops is growing ever wider.

The total amount of all printed material stored up by humanity comes up to nearly 100 million titles, including over 30 million books of different titles and nearly 10 million patents. Three million articles are published annually. Each year there appears in the world nearly 60 million pages of technical literature. This amounts to 100,000 volumes with 600 pages each. To store up this literature alone will require 300 km of shelves. More than 80,000 periodicals exist in the world. A hundred years ago it took only about 10 magazines to look through in order to compile the first five editions of a complete chemistry handbook but already in 1922 more than two thousand magazines had to be studied to put out the eighth edition of the handbook. In 1924 the section "Chemistry of Zinc" contained the reviews of slightly more than seven thousand magazines. From 1924 to 1956, i.e., in the course of 32 years the number of works have reached the figure of 25,000.

In the Soviet Union 7,000 titles of scientific papers come out annually in Russian, averaging 12 signatures each, 1,400 titles of textbooks, with 20 signatures each, and 1,200 scientific and technical journals.

According to UNESCO data, the Soviet Union holds the first place in the world in literature production, with the U.S.S.R. publishing houses producing one fifth of the world's total number of books. The 400,000 libraries of the Soviet Union contain 1,500 million books, magazines and newspapers.

Annually the world puts out 200,000 titles of books and magazines. Every 15-16 years library funds double. It

may be expected that in another 50-60 years the library literature funds will increase 15 to 20 times.

The State Lenin Library is the major library in the U.S.S.R. and the largest in the world. In recent years alone the annual influx of literature has increased from 500,000 to 800,000 volumes requiring 10 km of bookshelves.

In 1862, when the library was founded it had only 100,000 printed publications. In 1917 its number grew to 1,200,000. And by 1958 the library increased to 20,000,000 books and magazines. The library contains books in 160 languages including 85 languages of the peoples of the U.S.S.R.

In tsarist Russia during the entire course of its existence there appeared only 600,000 titles of books and magazines, but in the U.S.S.R. 40 years after the establishment of Soviet power there were already 1,350,000 titles of printed matter.

U.S. specialists cite the storage cost of book matter. The storage cost of one book for one year in an average U.S. library including amortisation of the building, installation of shelves, heating and lighting is two cents and the storage cost of a set of periodicals comes up to 40 cents.

A library ordering 500 periodicals and shelving 500 sets has to pay \$ 200 annually for their storage. The longer the storage time of these sets the greater the expenditures on their upkeep.

In the majority of cases the demand on periodicals is highest immediately after their publication, then drops sharply. The problem of printed matter storage becomes more and more acute with every passing year.

In this connection an attempt was made to solve the problem by recording certain publications on microfilms. To store 15 books or 8 volumes of periodicals requires 10 $dm^2$ of space, whereas a case for microfilms occupying 85 $dm^2$ can contain 612 volumes. The storage cost of one volume recorded on a microfilm, including the cost of the film, is three times cheaper than the storage of the original copy of this volume.

The cost of microfilming of one copy is equal to the cost of binding a book containing the same volume of material.

There are machines which store up several million microfilm stills.*

But microfilming failed to offer a way out. Film storaging requires special air-conditioners maintaining constant air humidity on the premises. When viewed, the film is subjected to wear and tear and its life is rather short.

The U.S. National Bureau of Standards has a special arrangement for selecting the necessary stills out of 10,000 stills recorded on a microfilm of only 10 sq. inches.

Of great interest are devices for the retrieval of information recorded on separate cards (minicards). These cards have certain symbols on their edges by which they are retrieved.

Original information is copied with the aid of special photo-automats. It is sufficient for each document (signature, paper or drawing) to have its own number. The photo-automats facilitate information storing since they make it possible to reduce the size of book storages, and make the retrieval of information much more cheaper and speedier. It is cheaper and easier to obtain a copy of some necessary book than to hunt for it in the second-hand bookshops or to wait for it to arrive from another library. Photo-xerographic machines producing cheap high-quality prints by dry method are widely used today.

A group of such photo-automats (several hundreds) with pneumatic delivery of prints made from microfilms by the given numbers can be used for automatic reproduction of books, magazines, records and booklets. Numbers (addresses) of separate chapters, articles, etc., will be determined by information and logical machines.

Photo-automats will in the near future radically change the library and reference archive service. A required text can be reproduced on the subscriber's TV screen shortly after the command with an address has been received, or a copy of a document printed by a photo-xerographic method.

Can you make a machine read publications like a man? The word "read" here may have various meanings. Sometimes a man reads in order to memorise something, as for

---

* E. Avakyan, E. Gartfield. *Special Libraries*, Vol. 48, No. 4, 1957.

instance, when a pupil reads the multiplication table or some verse or other. Sometimes he reads in order to select the necessary material for his practical work. Such selective reading can be only a cursory examination of articles, books and magazines.

More complex thinking processes take place when you read and study the material, when you evaluate its significance by comparing the text with the material (information) stored in the brain, etc.

Certain of the most simple of these functions can be carried out with the help of machines. First of all the machine can introduce printed information into its internal memory and read the text in the way a typist or a telegraphist reads it.

Recently "reading" automats were developed which identify letters, figures, hieroglyphs and other symbols in the books and convert them into numerical binary code (of the telegraph code type).

At first such automats were used for reading figures on bank cheques. This operation, very important in processing financial documentation, occupies quite a considerable place in the national economy. Thus, for instance, there were nearly 52,000 million bank cheques in circulation in 1960, and since each such document is handled about 10 times in the annual turnover, the cheques are counted in the course of a year more than 200,000 million times.

"Reading" is considerably facilitated by the fact that only 10 figures and several additional signs are to be identified. Moreover, all the signs on monetary documents can have special distinct features to facilitate machine identification. For instance, they can be written with the help of "magnetic ink".

A document first passes under the recording head and then under a number of reading heads arranged in a row (just like magnetic heads in a tape recorder). The signs recorded in magnetic ink passing under the heads induce in them electric pulses the volume of which depends on the shape of a sign. Combinations of long and short pulses make up binary sign code.

The machine's reading speed was 100 figures per second. Another automatic machine has been developed capable

of reading type-written text with the speed of 120 characters per second. Work is under way to develop automats for reading addresses written by hand on envelopes and postcards being sorted out at the post-office. The laboratory of electromodelling is also busy developing a machine which will read and convert the printed text of chemical journals.

There is a great future in the development of such automatic machines. They will serve as a sort of link-up element between the conventional written language and machine language (that is how we shall call written text converted into binary form, i.e., encoded for recording in the machine memory).

When the reading speed of a machine is 120 characters per second, it can encode nearly 100 signatures (1,600 pages). Working at this speed the machine can read and process in three months more than one million pages. It is far more convenient to feed filmed texts into the machine.

How do these machines read the text?

They comprise three units: a scanning light beam unit, an identification unit, and an output unit producing binary signals and sometimes printing identified characters for checking purposes.

Characters are scanned much in the same way as in a phototelegraph or television receiver. For instance, the light beam travels along the character and the reflected light is received by a photocell. Point by point, step by step the beam scans the entire area occupied by the character while the photocell registers and transmits to the identification unit long and short electrical pulses, proportional to the intensity of the reflected light. For example, in scanning a certain character 4,096 black and white (white spaces of the paper) dots are used. If the number of letters and symbols to be identified is 256, they can be coded by only eight binary signs ($2^8=256$). Therefore, we will obtain eight-digit binary code at the output unit. It should be noted that in this case 4,096 discrete scanning signals of one printed character are converted by the automat in the most rational way into eight binary signs.

In the identification unit scanning signals are being

automatically analysed by comparing them with a certain set of characteristic features compiled beforehand. They may be: dots over the letter *i*, crosses in the letter *t*, upper and lower dashes in the letters *l*, *T*, *l*, curved and inclined lines, etc.

The sequence of the letter node points with the indicated number of branches can also be made use of. Thus, there is one such point with three branches in the letter *T*, while the letter *H* has two such points and the letter *C* none. Hollows, holes, angles between various letter elements are also taken into account. Sometimes the shape of a letter distributed along this or that axis or its projection on the given line serve for identification purposes. In some machines letters are identified with the help of masks placed over them. Part of the letters visible or invisible from under the mask determine the code of the given letter. The letter *I* is recorded if the visibility of a part of the letter is above a certain threshold. If the visibility of the black part of the letter is below this level for the given mask, it will be the letter *O*. A set of masks makes it possible to distinguish between various letters.

In the light of the above the important role which a large-capacity machine memory is to play for modelling the process of image identification is quite evident. The thing is that the performance of human eyes and brains is far beyond the capabilities of modern technology. Let us compare certain data. The number of light-sensitive cells in the human retina is known to be nearly 130 million measuring $2\times60$ microns. It is considered that approximately only ten million cells participate directly in the analysis of images received by the retina.

The movement of the eyeballs plays an extremely important role in the process of vision. Continuous movement of the image on the retina is a necessary condition for vision. The process of vision consists of a constant change of fixations (97 per cent of the time, 0.2-0.8 sec each) and rapid change of fixation points (3 per cent of the time—"hundredths of a second"). Eyes shift their points of fixation nearly 120 times (every 0.5 sec) per minute. The shift value is small, about half a degree. When analysing the process of vision we come up against very interesting prob-

lems, for instance, how can we tell whether a line is rectilinear or not?

The seemingly paradoxical fact has been noticed that a man can determine a bend in a straight line with an accuracy 30 times greater than the size of one sensitive cell (eye cone).

This can be explained by the shift-like phenomenon of the process of vision called rectilinear scanning.

Using this, we can also explain how human eyes can tell whether two lines are parallel or not, whether a circle is true, concentric, etc.

In modernising the identification processes automatic devices of today use rather limited means. Instead of 130 million eye cells, mechanical devices use only 10,000 elements.

Nevertheless, machine letter identification even at this pioneer stage of its development is quite reliable and can satisfy practical requirements.

Unfortunately, very high reliability of letter identification is hard to achieve in small-capacity reading devices due to numerous defects of printing, dirty paper and distorted type. Identification of words in the text with the help of additional automatic dictionaries is much more reliable. In this case the degree of probability of the appearance of this or that letter among other identified letters of the word being read should be accepted. If the word *post* is being read, i.e., if instead of the third letter some other letter crops up, the machine dictionary can automatically correct the mistake and point out that the third letter should read "s". But the second letter can be "e", since there is such a word as *pest* in the dictionary. In this case only a more general analysis of the text according to the meaning can be of help. Fuller information will be expected from the dictionary for this purpose, which will be in its turn accounted for in the process of machine reading.

Thus, the conclusion may be drawn that best results can be obtained only by modelling the process of reading the text by a man who reads not by *letters*, but by *words* and even by whole sentences and uses the meaning of the entire text to correct spelling mistakes.

Depending on the combination of the identified characteristic features, the machine produces some binary code

*Table 1*

| Numbers in decimal form | Same numbers in binary code | | | | | Telegraph signs | |
|---|---|---|---|---|---|---|---|
| | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | Russian letters | Figures and signs |
| 1 | 0 | 0 | 0 | 0 | 1 | Change-over to Latin alphabet | |
| 2 | 0 | 0 | 0 | 1 | 0 | | Change-over to numbers |
| 3 | 0 | 0 | 0 | 1 | 1 | Я | 0 |
| 4 | 0 | 0 | 1 | 0 | 0 | Ы | 3 |
| 5 | 0 | 0 | 1 | 0 | 1 | С | . |
| 6 | 0 | 0 | 1 | 1 | 0 | Б | 8 |
| 7 | 0 | 0 | 1 | 1 | 1 | Р | — |
| 8 | 0 | 1 | 0 | 0 | 0 | Е | 2 |
| 9 | 0 | 1 | 0 | 0 | 1 | Ь | , |
| 10 | 0 | 1 | 0 | 1 | 0 | Г | 7 |
| 11 | 0 | 1 | 0 | 1 | 1 | М | |
| 12 | 0 | 1 | 1 | 0 | 0 | И | Ш |
| 13 | 0 | 1 | 1 | 0 | 1 | В | |
| 14 | 0 | 1 | 1 | 1 | 0 | Ф | Э |
| 15 | 0 | 1 | 1 | 1 | 1 | Н | Ю |
| 16 | 1 | 0 | 0 | 0 | 0 | А | 1 |
| 17 | 1 | 0 | 0 | 0 | 1 | Space | |
| 18 | 1 | 0 | 0 | 1 | 0 | Й | 6 |
| 19 | 1 | 0 | 0 | 1 | 1 | К | |
| 20 | 1 | 0 | 1 | 0 | 0 | У | 4 |
| 21 | 1 | 0 | 1 | 0 | 1 | Т | Ч |
| 22 | 1 | 0 | 1 | 1 | 0 | Ц | 9 |
| 23 | 1 | 0 | 1 | 1 | 1 | Щ | / |
| 24 | 1 | 1 | 0 | 0 | 0 | П | J |
| 25 | 1 | 1 | 0 | 0 | 1 | З | : |
| 26 | 1 | 1 | 0 | 1 | 0 | Х | + |
| 27 | 1 | 1 | 0 | 1 | 1 | Л | = |
| 28 | 1 | 1 | 1 | 0 | 0 | О | 5 |
| 29 | 1 | 1 | 1 | 0 | 1 | Ж | |
| 30 | 1 | 1 | 1 | 1 | 0 | Д | 0 |
| 31 | 1 | 1 | 1 | 1 | 1 | Change-over to Russian alphabet | |

representing the number of the identified character. This code is reproduced at the machine output as an electric pulse which triggers the printing device at the output.

In more than a hundred years of the development of telegraph technique the system of writing down letters and figures with the help of binary signs has been thoroughly developed and perfected.

Let us see how a modern telegraph set works. Each letter or figure is numbered. Only five binary signs are used to transmit the signals. Each binary sign represents a definite power of the number 2. A five-digit binary number is quite sufficient for the text transmission.

Table 1 shows the use of binary signs (binary code) in a telegraph set.

The figure 1 (binary sign—00001) is used as a transition sign to indicate that Latin letters will follow immediately after it. The figure 2 (binary sign—00010) shows that figures are to follow. The figure 31 (binary sign—11111) indicates that Russian letters are to be transmitted.

Given in Table 2 is an example of encoding the Russian word НАУКА (Science).

The reading automatic machine mechanises the work of a typist and telegraphist.

It takes months to learn Morse code. A highly-skilled telegraph operator codes and tapes out on the key dots and dashes corresponding to letters of the text with lightning speed.

A binary encoder operates much in a similar way converting (i.e., encoding) one of the 31 positions after another into the figures 1 and 0 of the binary code.

*Table 2*

| Letters | Bits | | | | | Decimal |
|---|---|---|---|---|---|---|
| | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | |
| Н | 0 | 1 | 1 | 1 | 1 | 15 |
| А | 1 | 0 | 0 | 0 | 0 | 16 |
| У | 1 | 0 | 1 | 0 | 0 | 20 |
| К | 1 | 0 | 0 | 1 | 1 | 19 |
| А | 1 | 0 | 0 | 0 | 0 | 16 |

The process of mental activity of a telegraph operator is automatically taken care of by a device called an *encoder-decoder* (Fig. 3). It consists of a number of electrical cou-

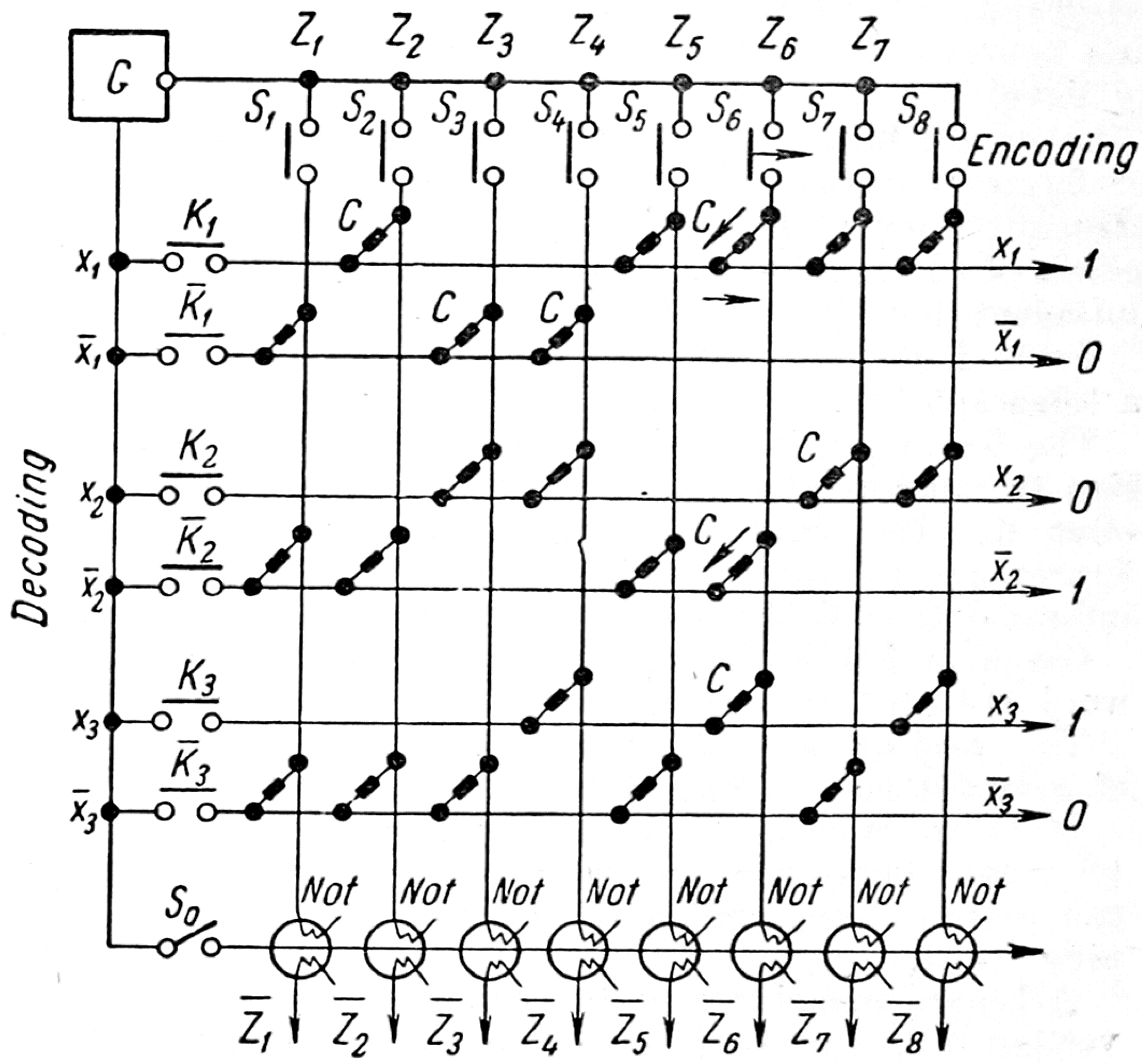



*Fig. 3.* Electrical circuit for encoding (conversion of a number of key positions into binary code) and decoding (reverse conversion of binary code into one of the key positions):

$G$ — power source; $S$—encoding keys;
$K$—decoding keys; $X$ and $Z$—bars;
$C$—coupling elements between bars

plings $C$ between the input and output bars. Here is how it operates. The circuit comprises 8 keys $S$ and bars $Z$ for the coded symbols and three pairs of keys $K$ and bars $X$ for their binary code. Couplings $C$ are arranged according to Table 3.

Table 3

| Bar $Z$ numbers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $X$ (direct code) | 000 | 001 | 010 | 011 | 100 | 101 | 110 | 111 |
| $X$ (inverted code) | 111 | 110 | 101 | 100 | 011 | 010 | 001 | 000 |

For further discussion we introduce the terms direct code and inverted code. Any binary number can be converted so that each unit in it is substituted by a zero and vice versa. Suppose that number 101 is given; then after the substitution we shall have 010. The new number is called an *inverted* code in relation to the initial number code which we shall call a *direct* code, and the whole process is called *inversion*.

Suppose that symbol $S_6$ is given. We close key $S_6$ and leave the rest of the keys open. This position of the keys is recorded as follows:

$$S_1=0,\ S_2=0,\ \ldots, S_5=0$$
$$S_6=1,\ S_7=0,\ S_8=0$$

As we have already said, the state *closed* is recorded as 1, and *opened* as 0.

Bar $Z_6$ excites certain bars $x$ via couplings $C_6$ with key $S_6$ closed; the state of bars $x$ may be expressed by binary signs (on the right in Fig. 3). The presence of excitation is recorded as 1, and the absence as 0:

$$x_1=1,\ x_2=0,\ x_3=1;$$
$$\overline{x_1}=0,\ \overline{x_2}=1,\ \overline{x_3}=0.$$

The state of these bars determines the direct code 101 of the symbol $S_6$ and its inverted code 010. The closing of any key $S$ determines its respective code, according to Table 3. Herewith lies the core of the encoding process.

The reverse process, the *decoding* process, proceeds as follows: source $G$ is connected to certain bars $X$ with the help of keys $K$, specifying one of the *unexcited* bars $Z$ whose number and symbol are the result of the decoding.

Here is an example: we shall set the keys $K$ according to code 101 and the inverted code 010:

$$K_1=1,\ K_2=0,\ K_3=1;$$
$$\overline{K}_1=0,\ \overline{K}_2=1,\ \overline{K}_3=0.$$

All bars $Z$ except bar $Z_6$ will be excited via coupling $C$. Therefore they will have the following arrangement:

$$Z_1=1,\ Z_2=1,\ldots,\ Z_5=1,$$
$$Z_6=0,\ Z_7=1,\ \text{and}\ Z_8=1.$$

Their state can be inverted with the help of key $S_0$ (left-hand, bottom corner, Fig. 3) and elements *NOT*. Thus the decoding process consists in finding one of the bars $Z$ by the given binary code with the help of keys $K$.

In the given example the number of bars $Z$ is 8; in the binary system this corresponds to $2^3$. Any encoder or decoder comprises $2^n$ bars $Z$ and $2^n$ bars $X$. In telegraphy $n=5$. There are cases, for instance, when $n=6$, 7, 8. The number of coupling elements $C$ which act as memory elements is $n2^n$. In our example it is $3\times2^3=24$. In the telegraph system it is $5\times2^5=160$.

A far greater number of encoded binary signs has to be used for Chinese and Japanese characters since their number runs into several thousands.

The system of hieroglyphs suggests that information can be written down in the memory of the information machine not by separate words, but by code expressing entire words and part of the sentences. Thus, for example, to record 1,000,000 words and phrases with the help of a *word* code a 20-digit binary code is required since $2^{20}$ tots up to a number greater than a million.

An average Russian word consists of nine letters. To write it down in letter code requires $9\times5=45$ binary signs, i.e., twice more than in word coding.

Machine code is the language of figures (binary signs). Encoders convert letters and figures into binary signs and decoders read and convert them back into letters and figures again.

The transition from discrete scanning signals depicting printed information to discrete signals of the binary code, even of the simple letter telegraph code, makes for greater economy and considerably facilitates information machine processing.

*Magnetic tapes* are the cheapest and simplest devices for recording and reproducing binary information. As these tapes are used today in tape recorders mass-produced for general consumption, the process of production and the quality of tapes are constantly improving and their cost is becoming less.

In information recording, special broad multi-track tapes are used with a highly-glossed surface to minimise wear-and-tear. The tape is an acetate film coated with magnetic oxides. Sometimes ordinary film as well as nylon tape are also used.

Magnetic tape specifications

| | |
|---|---|
| Length of one reel | 720 m |
| Width | 16 mm |
| Number of tracks | 14 |
| Speed | 2 m/sec |
| Reading speed | 10,000 pulses per sec on each track |
| Recording density | 5-8 signs per 1 mm |
| Starting time | 5 millisec |
| Stopping time | 2 " |

Nearly 80 million binary signs stored on one reel can be reproduced in about 6 minutes. Hence 1,000 million signs can be recorded on 12 reels.

However, it takes considerable time to retrieve part of the information from the tape by the given address since it requires several minutes on the average to rewind half of the tape.

Magnetic tapes can be used as a large-capacity external memory of information machines. Reading devices record on them vast number of publications. Newly published books and journals can be encoded in binary code beforehand, while being prepared for the press, so that the text can later be used in information machines.

Already today type-setting in large printing houses begins with the conversion of letters and figures into binary code in order to automate the process. The equipment used is similar to that of the telegraph. Each letter, or any other typographical sign of the text, is given its number in the binary form on the punched tape. These tapes can be easily checked and corrected if necessary. After a final check-up they are fed into automatic input devices of the printing machines (for example, linotypes) and the reproduced binary signs actuate the machine's electromagnetic drive.

As distinct from telegraph tapes, typographic punched tapes have a greater number of tracks for recording binary signs since in type-setting the Russian, Latin and Greek alphabets are used along with a vast number of special signs (integrals, differentials, etc.).

Punched tapes of the automatic type-setting equipment can be used for recording the content of books and journals on magnetic tapes. Later on this material can be further processed in order to extract from it valuable thoughts, ideas, generalisations and analogies. This is where we need information and logical machines with a certain amount of initial information stored in the machine long-time memory.

The capacity of the external memory magnetic tapes in some of the information machines has been brought to 300 million words, and the access time to 20 sec. This seems to be very little, but if we compare this time with the access time of 10 microseconds which was achieved long ago in a purely electronic memory, the ratio between these values exceeds one million. If we compare the machine's internal memory with that of a man who can reproduce an image in his memory by spoken word within a second, his referring to a library (his "external" memory) and obtaining information from there in about six months will give us an approximate comparison to a ratio of one million. Therefore the work of an information machine with a high speed internal memory and a slow-access external memory (external magnetic storage) may be interpreted as the process of mental activity of a man who, besides information accumulated in his memory, has to refer to a

library for additional data, hoping to obtain answers in six months after each enquiry he makes.

To cut down the access time, an arrangement (magnetic drum or magnetic discs) with smaller capacity is used. The number of simultaneously connected heads in the magnetic drum may reach 256. One of the magnetic heads can be connected to the given address with the help of a decoder. In this way a single coordinate memory address system can be realised in which magnetic drum tracks will serve as cells. The total memory volume in a system of this kind can be brought up to half a million bits, with an access time to one of the 256 addresses of between 2 and 50 milliseconds (the time of one revolution of the drum).

In recent years a more capacitive address system of recording on magnetic discs has been developed. The RAMAC system of the IBM company has 50 discs with 100 concentric magnetic tracks each. Two coordinates specify the position of magnetic heads which are mechanically shifted by a pneumatic drive. One coordinate establishes the cylinder number, the other one, the track number. The total number of memory cells comes up to 5,000 (50 discs ×100 tracks). The time of operation of a head is about half a second (the memory cell access time depends in the main on this factor). The total capacity of 5,000 memory cells in the machine reaches 5 million bits.

There is yet another machine which employs five mechanically moving frames with 2,000 magnetic tapes arranged on them. All in all each frame has 10,000 lengths of magnetic tape, with 200 sections ("pages") each. Eight tracks, each 0.5 m long, operate simultaneously on 16 mm tapes. Thus the machine operates as a three-coordinate address system. One coordinate determines the number of a frame (from 1 to 5), the second one determines the number of a "page" (from 1 to 200), while the third gives the tape number in a "page" (from 1 to 10). All in all there are 10,000 addresses (5 ×200 ×10). The total capacity of the memory is nearly 200 million signs, since 2,500 bits can be recorded on each of the eight tracks.

The frames are actuated mechanically with the help of a hydraulic drive.

Photo-telegraph apparatus developed in the early 'twenties are the most simple systems with machine memory. Recorded information is reproduced in them with the aid of a light beam travelling along the drum or a flat surface on which information has been recorded. The reflected light beams hitting a photocell convert light pulses into electrical pulses.

In photo-telegraphy each square decimetre of an image is divided into 250,000 or 490,000 elements scanned by a spot of light 0.2 and 0.14 mm in diameter respectively.

The scanning speed of the existing photo-telegraph apparatus is 0.5-1.0 $dm^2$/min; this corresponds to 40,000 signals per second.

Another example of the reproduction of machine records is the film projector which uses film instead of paper. The film makes it possible to record the signal on the rather small area of 0.025 $mm^2$, and if a super-high speed film is used the area can be reduced to a mere 0.004 $mm^2$.

Photo-telegraph apparatus and film projectors use light to record and reproduce information. Great recording density, visual control and a comparatively high speed of reproduction are the advantages of these systems. However, the life span of a tape (film or paper) is extremely short, only a few thousand reproductions are possible.

## Internal Memory

Just as human memory apprehends outside information with the help of certain analysers, filtering and processing it in accordance with life-long practice, the internal memory of the information and logical machines should accumulate only valuable information correspondingly processed for further use in some field.

The human brain consists of mechanically immobile cells. The internal machine memory, just like all other elements of the electronic information machine, consists of mechanically immobile and hence high-speed and durable elements.

It stands to reason that the cost and dimensions of elements of the internal machine memory are considerably

greater than the cost and dimensions of the external memory elements (magnetic tape), but this is compensated for by the results obtained.

We distinguish between long-time or permanent memory and volatile or operative internal memory.

In the case of the permanent memory, information is recorded outside the machine with the help of a keyboard or a printing device, while inside the machine this information is being read out over and over again. In this aspect long-time or permanent memory is similar to books, journals, and other printed and written matter, gramophone records, films, and punched cards. All these information carriers have one thing in common: they allow the reproduction of information once recorded on them any number of times.

Operative or volatile machine memory reproduces information with similar ease and rapidity, erases it and records new information. Of the types of memory known to us magnetic tapes, discs and drums possess this property.

A mechanically immobile internal memory unit intended for temporary storage and rapid, reliable, and accurate reproduction of a vast amount of information serves as the basis of an information and logic machine. A machine memory of this type may employ various elements of an electrical circuit. To record a single signal, use can be made of the absence or presence of a definite element in the common coupling system, or electrical or magnetic properties of the elements themselves, or their steady state.

Coupling elements are usually used to record binary information in the electrical permanent machine memory.

If we accept that the presence of the coupling element corresponds to the recorded code signal 1, then upon reading out the information, when the text is electrically reproduced, the excitation of the circuits with coupling elements (recorded units) should induce electrical pulses at the output bars. On the contrary, such pulses should not appear when the circuits where coupling elements are absent (recorded zeroes) are induced. Thus the text in the machine memory can be reproduced through a combination of electrical signals corresponding to the arrangement of coupling elements in the electrical circuit of the memory unit.

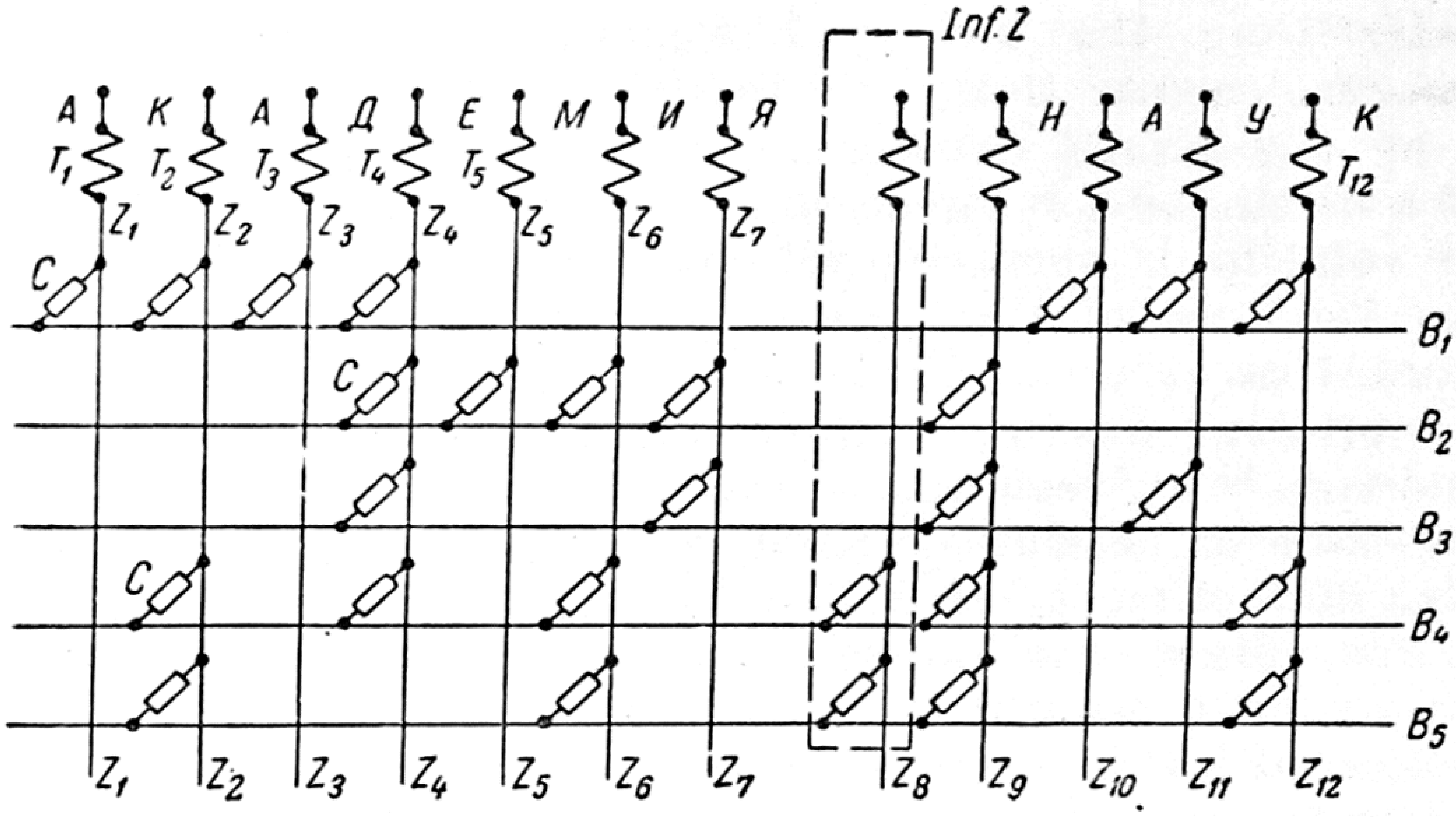



*Fig. 4.* Key diagram of coding words АКАДЕМИЯ НАУК (Academy of Sciences) with the help of coupling elements in the long-time memory

$Z$—memory cell address bars (one cell outlined by broken line is designated by *Inf Z*); $C$—coupling elements; $B$—recording bars; $T$—current sources for exciting memory cells

Shown in Fig. 4 is the diagram of text reproduction to illustrate the process of information recording and reading-out. The text is an electrical circuit comprising address bars $Z$, output, reading bars $B$ and coupling elements $C$.

Coupling elements link up bars $Z$ and $B$ in accordance with a definite code of the recorded and stored information.

This means that if we want to record for instance words АКАДЕМИЯ НАУК (Academy of Sciences) expressed in telegraph code we must arrange coupling elements between address bars $Z$ and output bars $B$ as shown in Fig. 4.

Information is read out from bar $Z$ upon its arrival at the bar of an electrical read-out signal from the address system (not shown in the figure).

Thus, when the read-out signal arrives at each of the bars $Z_1$, $Z_2$, . . . $Z_{12}$, information subsequently appears at the output bars $B_1$, $B_2$, . . . $B_5$ in the form of a binary code of one of the recorded letters. It goes without saying that not only one letter can be recorded on one bar $Z$ but several letters, a word and even a phrase.

In this case as soon as the read-out signal arrives at one of the address bars the entire information in binary code corresponding to the recorded phrase will simultaneously appear at the output bars.

We shall call the combination of coupling elements arranged in a definite sequence along one bar $Z$ a memory cell (see Fig. 4), and the information stored in this cell we shall call the information unity or word, denoting it $Inf\,(N)$, where $N$ is the number of the memory cell. The time of operation of a single reading-out signal we shall call a memory operation cycle (the time of information retrieval).

In the memory under discussion, as many pulses are read out during one cycle as coupling elements, inserted between one address bar $Z$ and the reading-out bars $B$. Practically nearly one thousand bits can be read out simultaneously.

The coupling elements should pass the read-out signal from the address bars to the output bars; elements of electrical circuit which pass electric signals (resistors, capacitors, inductances, valves, transformers and chokes) can be used for this purpose.

In Fig. 5$a$ resistors $R$ play the role of coupling elements. When transformers $M$ are used as coupling elements,

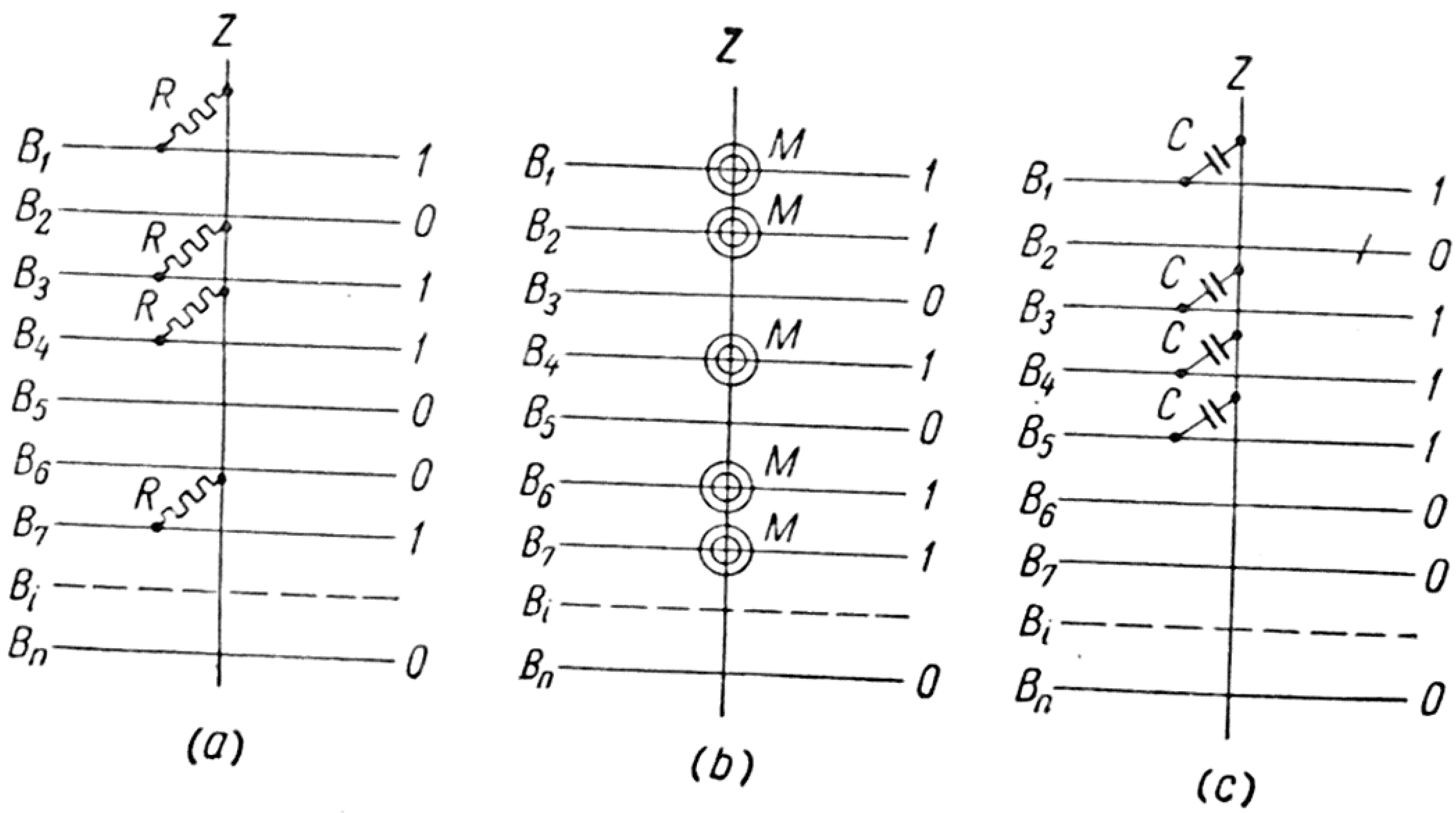



*Fig. 5.* Various coupling elements of the long-time memory

$a$—resistors $R$; $b$—transformers $M$; $c$—capacitors $C$

they should be connected as shown in Fig. 5*b* in order to record the 1101011 code.

The cores of all the coupling transformers of one memory cell can be combined into one common core.

The connection of capacitors $C$ as coupling elements, shown in Fig. 5*c*, is of special interest.

Diodes, in particular crystal diodes, with a comparatively high resistance ratio for current flow in forward and backward directions can also be used as coupling elements. However, these devices are, as yet, expensive.

Let us discuss capacitive memory as one of the variants of long-time memory.

## Long-time Capacity Memory

Figures and text can be recorded on sheets of paper with the aid of current-conducting signs (made by metallising capacitor electrodes).

The key diagram of the capacitive memory developed in the Laboratory of Electromodelling is shown in Fig. 6. Capacitors $C$ serve as coupling elements. For simplicity, all the elements shown on one sheet of paper and comprising a single memory cell are arranged along one vertical line, the bar ($Sh_1$, $Sh_2$, . . . $Sh_5$).

Information is recorded by connecting or disconnecting the capacitors $C$ in the circuit. First of all we can print the sheets with all the connections, and then as the need arises punch electrode couplings with the bars.

In case there are many information machines in the country the sheets with coupling circuits printed according to the given code should be used.

In this case bars $Z$ can be printed on one side of the tape with the help of an electrically conductive layer, bars $B$—on the other side, while couplings in the spots where units are to be recorded should be printed by circles of a conductive layer. This method of recording makes it possible to reduce the size of the memory units considerably.

The recorded information is read out with the aid of voltage pulses induced by the address control signals in the transformer secondaries $T_1$, $T_2$ , . . . $T_5$, etc.

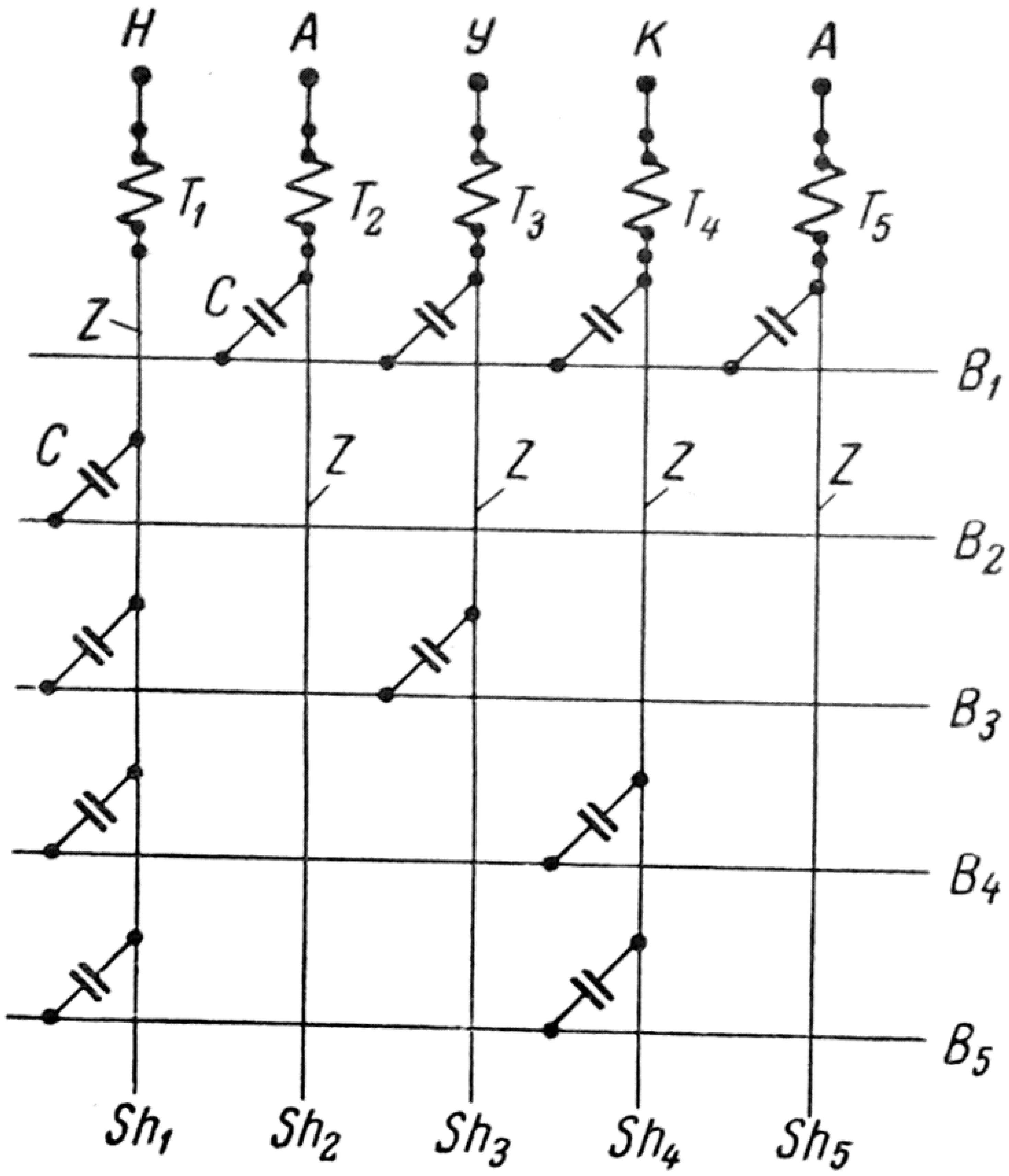



*Fig. 6.* Key diagram of the long-time capacitive memory

When one of these transformers, for example $T_1$, is excited the voltage acts upon the common electrode (bar $Z$) of sheet $Sh_1$.

The capacitive memory units are made up of metallised punched cards. One unit can contain, for example, 512 or 1,024 cards connected by common read-out bars.

Fig. 7 shows one such punched card and one plate with read-out bars, shown by strips, situated perpendicular to it.

Coupling capacities are formed between the metallic surface of the card slot and the metallic surface of the read-out bar. The dielectrics are the air gaps and a layer of paper or film covering the bar.

Information is recorded on the card by punching it in those places where zeroes should be. In these spots metal is cut out of the slot surface and the air gap is widened

(e.g., the punched holes on the card in Fig. 7 opposite 1st, 5th and 8th bars counting from bottom). The capacitance between these bars and the card metal drops sharply as compared with the coupling capacitance in the absence of perforation. When a voltage pulse is fed to the entire card via the read-out bars situated between all the card slots, strong unit (1) signals are induced; in those places where there is no perforation, weak zero (0) signals appear in all the bars situated opposite the perforated slots.

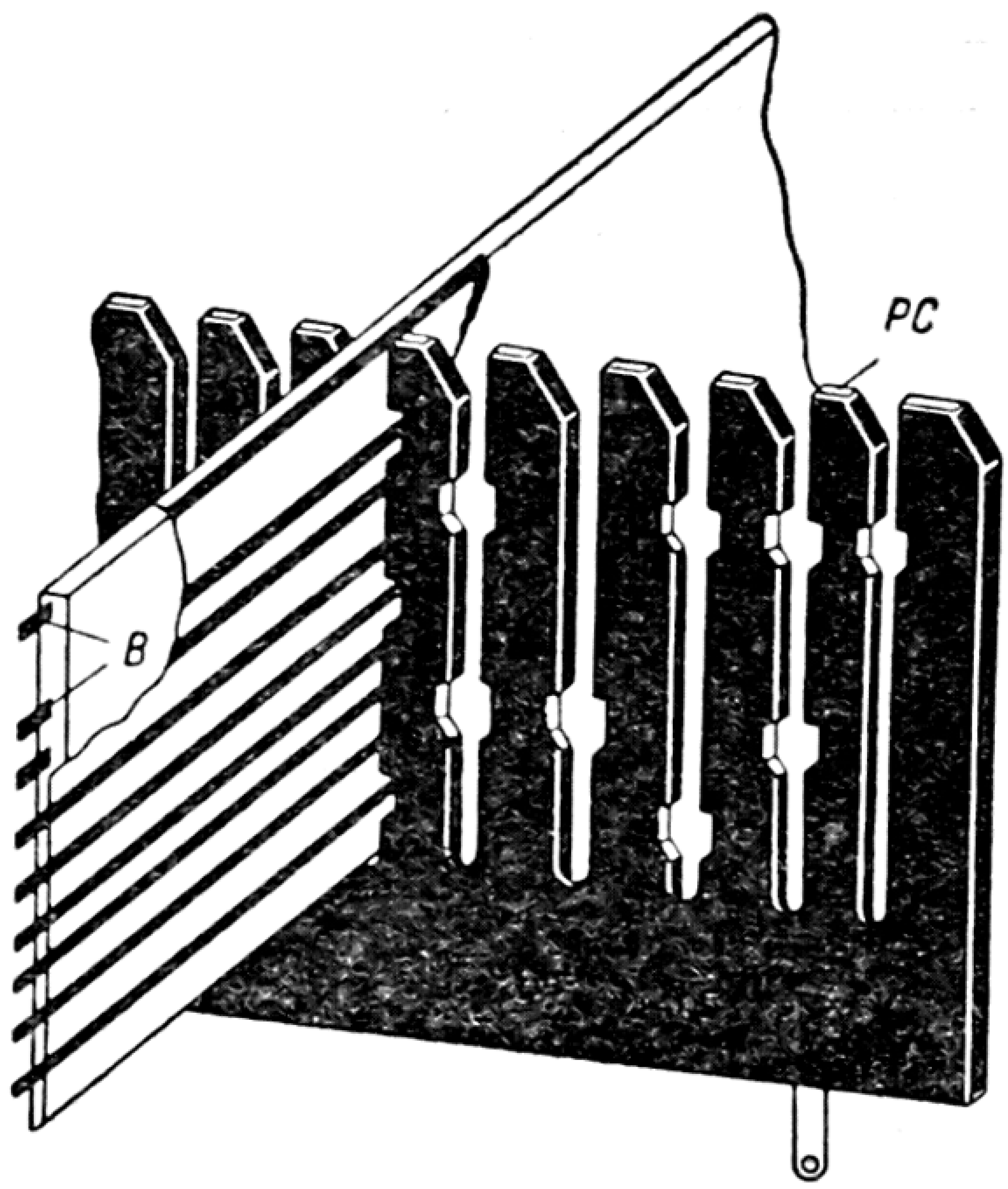



*Fig. 7.* The design of capacitive memory when punched card *PC* and read-out bars *B* are mutually perpendicular

The unit comprises a number of fixed plates with bars. Information carrying pre-punched cards (resembling combs) are packed into a unit with an output conductor from the address system connected to one common electrode of each card.

These units make it possible to add new cards to the memory store or to remove cards at will.

If the cards are not split all the way they become more rigid and hence more bits can be packed on one punched card. But in this case the plates with bars have to be inserted into the card slots or, vice versa, the cards have to be placed on these plates.

Shown in Fig. 8 is the simplified diagram of a unit with the capacitive punched cards split at the end.

In the capacitive memory system of another design the capacitive coupling between the address and read-out bars is eliminated by screening in those places where zeroes are recorded and read out.

Fig. 9 shows a key diagram of the capacitive memory with the screening card. Plates with address and read-out

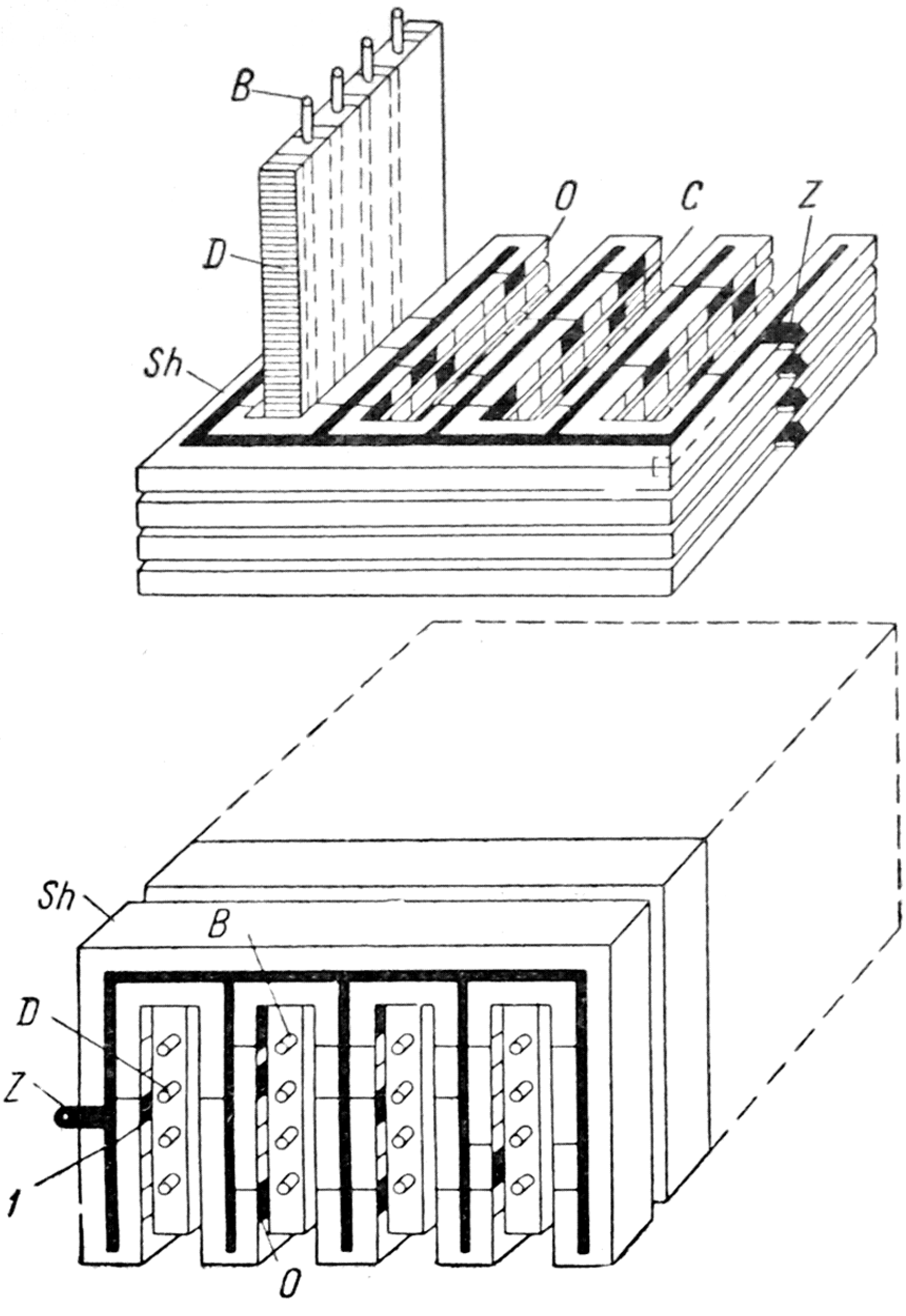



*Fig. 8*. Key diagram of the design of a long-time capacitive memory unit employing split sheets (combs)

*B*—information read-out bars; *D*—dielectric (sheet); *Sh*—split cards (combs); *C*—flat electrodes of the elementary capacitors; *O*—zeroes are recorded here

bars (bars shown in Fig. 9 are without plates) serve as rigid elements of the unit. Each pair of plates forms a sort of "pocket" inserted into which is a metallised card of

the screen *PC*. To record units (1) holes can be punched in the card in those places which correspond to the cross points of the fixed mutually perpendicular address and read-out bars. These holes allow electrical lines of force to penetrate from the address to the read-out bars. The capacitance at these spots is approximately 0.1 pf. In other places the

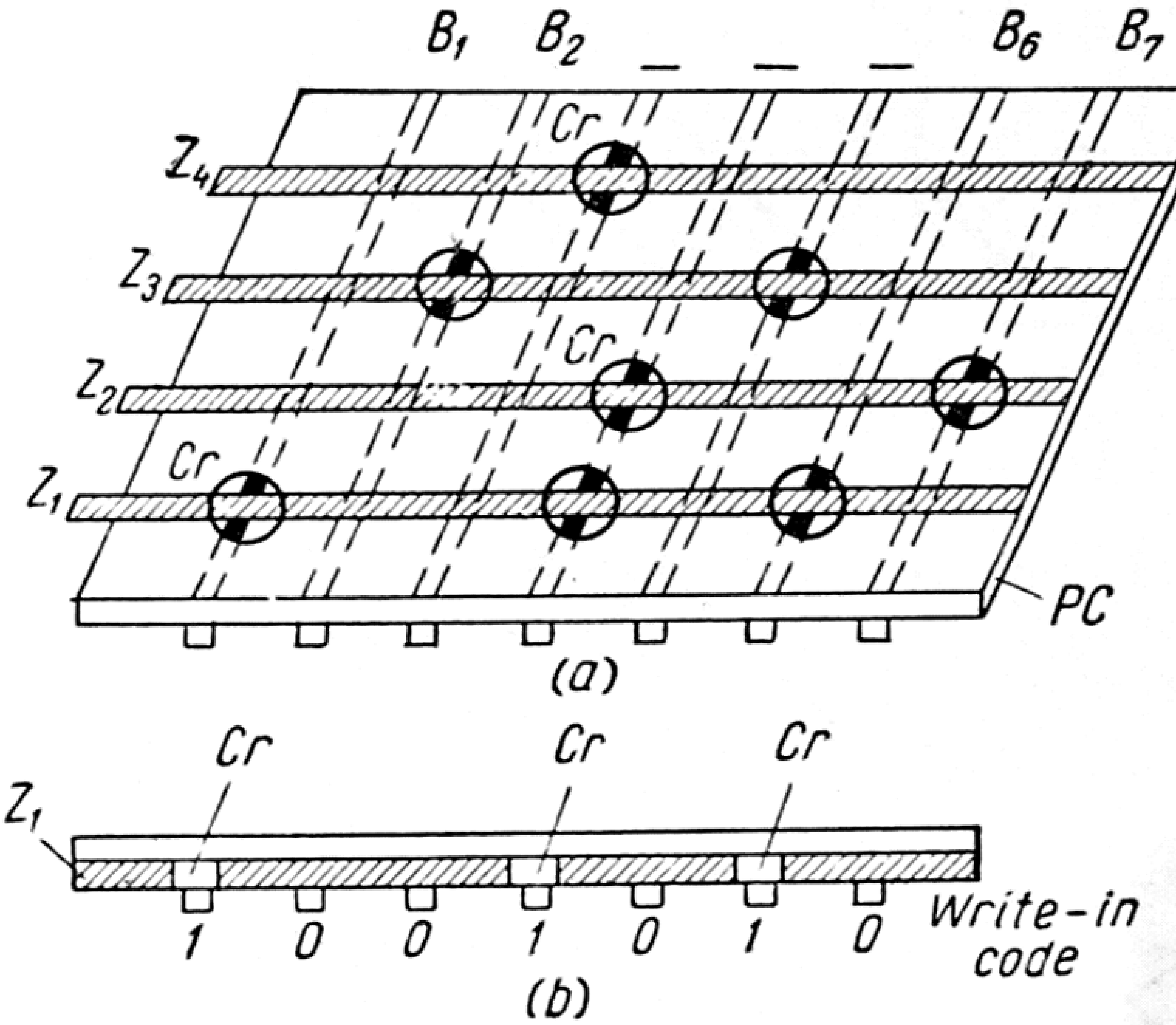



*Fig 9.* Diagram of a capacitive memory with information being coded in punched cards *PC* screening address bars *Z* from read-out bars *B* at the cross nodes when zeroes are recorded. Units are recorded by punching cards at crossings *Cr* (see coding 1C01010 along bar $Z_1$)

*a*—top view; *b*—side view

metal surface of a card screens the electrical field between the bars.

The plates form an immovable cassette containing practically 500 cards. They all should be earthed following their installation in the machine.

The screen-punched cards exactly correspond in size to the conventional 80-column cards of the computers. Each of them can have as much as $80\times12=960$ holes. Thus, a cassette of 512 cards can contain information amounting to half a million bits.

The ratio in strength of signal "1" to "0" is greater than 10. This is quite satisfactory for the stability or reliability of the whole system. The access time of the unit containing 10 million bits is 10 microseconds.

Standard size punched cards can be manufactured at the works which put out equipment for the computers for punching (recording), sorting, checking, reproducing and for other operations.

These two types of the capacitive system of metallised punched cards are shown here to illustrate the two different ways in which information can be arranged; in the plane (Figs 7 and 8) and in the line (Fig. 9).

It is rather difficult to design the unit constructionally when the memory elements intended for recording a great number of bits in one address cell are arranged in a line. Thus, for instance, if one memory element takes up 2 mm, the length of a cell containing 512 elements will exceed one metre. Therefore, in the screen card system, the number of bits in one cell depends on the card length and consists of only 80 bits.

In the case of the on-the-plane arrangement (the comb system in Figs 7 and 8) reading-out bars $B$ are positioned in the third dimension. With one memory element requiring 2 mm, 1,024 elements will take up $(64 \times 64)$ mm$^2$. In one particular case a 960-bit information can be arranged on one punched card which plays the role of a memory cell.

The arrangement of information of one cell in a plane is of the greatest importance, since the number of address cells can be cut down and more information obtained per cycle (here 960 bits instead of 80).

It should also be mentioned that when recording on screen cards, more power is spent on parasitic capacitive earth currents and the volume of output signals is about 10 times less, the conditions remaining the same in both cases.

Other variants of capacitive memory are also known.

The smaller the elementary capacitive coupling, the lower can be the power spent on control and information retrieval. If the power is the same, the frequency and hence the speed can be increased. The system can operate up

to very high frequencies (of the order of scores of millions cycles).

Output signals can be increased considerably by using the resonance at the capacitive system input and output or by increasing the number of cards read out by the same amplifiers, the value of the output signal being the same.

Future possibilities of the capacitive memory depend on the development of microminiature electrical circuits.

## Inductive Long-time Memory

An inductive coupling can be used instead of a capacitive coupling between the address and read-out bars (see Figs 5*b*).

Ferrite rods 1 mm in diameter and 6 mm long positioned at bar crossings in different planes to record units intensify the inductive coupling in one of the machine variants. The bars can be printed on plastic plates or woven from wires.

In another variant coupling is provided with the help of Ш-shaped ferrite cores with inserted read-out wires. The wire is inserted into the left slot of the core for recording units, and into the right one for recording zeroes. Each core also has an input address primary. When current flows through it voltage pulses induced in the read-out wires of the right and left slots will have different polarity (phase). When the induced pulses are read out, the positive sign plays the role of 1 and the negative of 0.

Thus, the polarity of the output signal pulse reproduces the state of the read-out wire in the Ш-shaped core, i.e., what has been ordered by the "record" signal.

The role played by the windings can be reversed and then some of the windings on each core will perform the read-out functions, while the wire passing through all the cores will carry the address or input functions. The access time of a unit containing half a million signs will be several microseconds.

## Photo-electronic Long-time Memory

The design of a rather capacitive "photoscopic memory" is similar to photo-telegraph read-out devices. It comprises a glass disc with information recorded in bit form on the tracks running along its edge. The disc rotates uniformly and recording is carried out by a sequence of black and white squares with sides of several microns in length.

The reading device comprises a cathode-ray tube whose beam is shifted by a uni-coordinate address system which sets it on one of the tracks. The beam reflected from the black-and-white squares hits a photocell. The reproduction speed approaches 1,000,000 squares per second. However, it takes quite a lot of time for the beam to be positioned on the right track and pointed at the right spot on it. The access time on an average is approximately 30 milliseconds.

It is rather complicated to record information with the help of this system. First of all a multi-million mass of bits should be prepared and checked with the help of punched cards; then it should be recorded on magnetic tape and from it onto the film; it is only then that the information is transferred to the disc.

The cathode-ray tube can be positioned in a definite point of the screen with very high accuracy if feedback is used to correct the address. Thus the address system can be used to set the tube beam in one of the $128 \times 256 = 32{,}768$ positions.

The electron beam can be used not only for reading out, but also for the photo-recording of a binary sign on a sensitive plate. It is reflected from a black or white spot, hits the photocell and is converted into an electrical signal "1" or "0".

One and the same beam from the address tube can be distributed with the help of an optical system among many such plates with separate receiving reading photocells (32 or 64), and simultaneously (in parallel) information read out from all these photocells. That is how a long-time photo-electronic memory is obtained storing from 1 to 2 million bits of information and retrieving it with a speed of several microseconds.

In this system binary signals of the code address have

to be converted with a high degree of accuracy into voltages at the electrodes deflecting the beam.

These are the first steps in developing long-time memory. In the near future scientists will design devices which will make use of the properties of memory cells at very low temperatures (about $4^0$K, the temperature of liquid helium) or be based on some other physical properties. The development of units 1 $m^3$ in dimension containing 1,000 million bits and capable of retrieving information in 10 microseconds will mark a technical revolution in many fields of automation.

## Memory Elements of Volatile Memory

Memory elements have two stable states which are used for recording single code signals of information.

At any given moment of time the element can be only in one stable state of the two. The element passes from one state to the other under the action of the incoming signals.

The change of state of the memory element is characterised by a curve representing the dependence of the definite parameters of the element on the incoming signals for each type of the memory elements.

In the general case the curve representing the change in the state of an element has a loop form where one branch of the loop signifies the transition of an element from 0 to 1 and the other, the transition back (Fig. 10*a*).

The process of operation of such elements with a loop-shaped curve representing the transition from one stable state to the other can be illustrated in the example of two escalators *E* arranged as shown in Fig. 10*b*.

The right-hand escalator moves only upwards while the left-hand one only downwards. The initial stable positions are 0 below and 1 on top.

To get from 0 to 1 a man has to make a few steps to the right (from the 0 position) and then go up in the escalator where he can stay as long as he likes (position 1). To get back to the initial position 0 he must walk to the left and take the escalator down.

The transition from one stable position to the other demands a certain effort.

Now we shall discuss some of the magnetic and capacitive memory elements. Information (0 or 1) recorded in such an element is preserved for an indefinitely long period of time provided the element is protected from outside influence.

When the read-out control signal arrives, the recorded code signals 1 are lost since the element passes over into

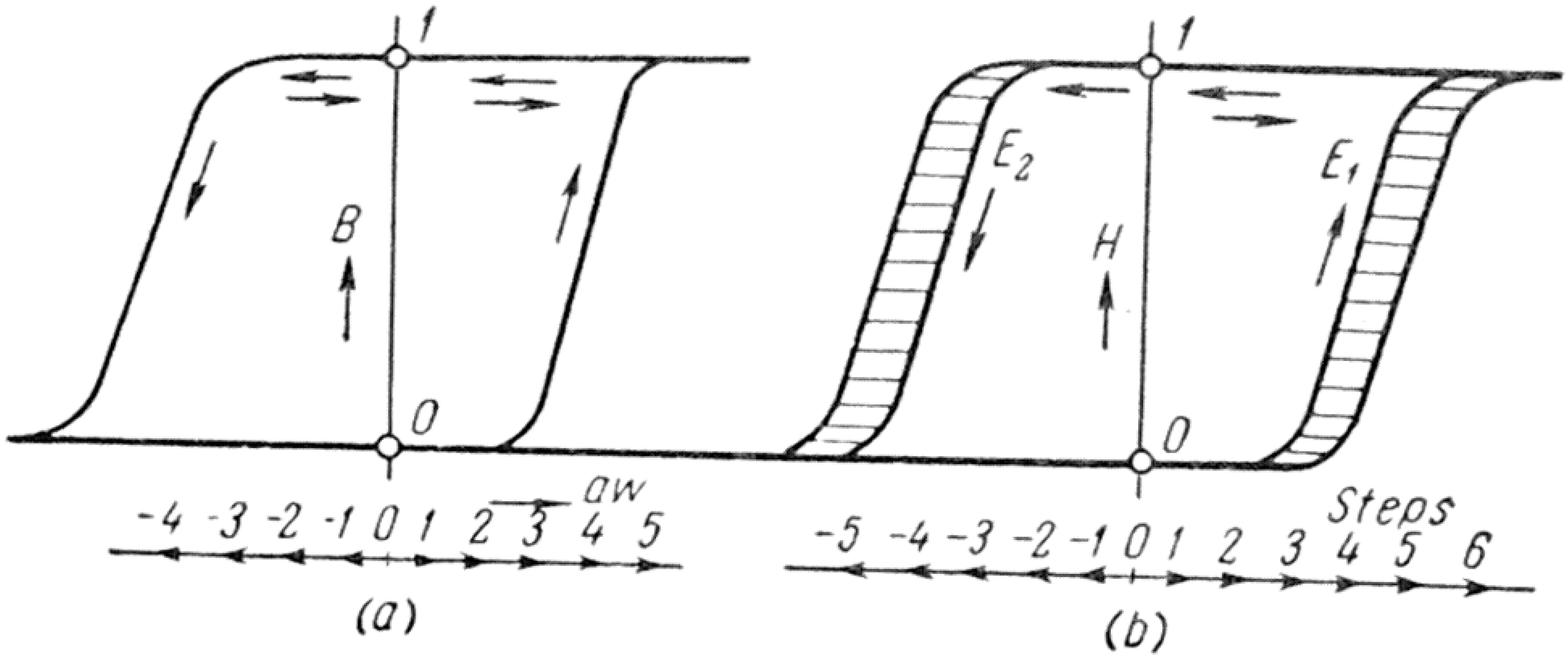



*Fig. 10.* An example illustrating operation of the volatile memory element

*aw*—ampere-turns, *B*—parametre, *H*—height; $E_1$ and $E_2$— escalators

another stable state (0). Therefore, the memory element can be used repeatedly for recording and reproducing information.

For the memory element to pass from the state 0 to the state 1 a control signal determined by five units (0-5) in Fig. 10*a* should be fed to it. This signal should be greater than some threshold value beyond which the parameters change suddenly (see the example above with escalators). When the signal arrives determined by (1) (referred to the beginning of coordinates), the element remains in state 0. When a signal is greater than two 1s the element will change over to 1.

Take the same example with the escalators (Fig. 10*a*). If a man from point 0 wants to go up the escalator, he will have to cover all the way from point 0 to 2. Assume that this distance is equal to 2 steps. If the man makes 1 step he will fail to reach his destination. Should he take 2 steps he will reach the escalator.

There are many elements of electrical circuits which possess loop characteristics of parameter changes.

Ferrites. Ferrites are made of a compressed and baked magnetic powder compound comprising iron oxides and oxides of divalent metals (nickel, manganese, magnesium, etc.). Ferrites possess high electrical resistance with insignificant losses due to eddy currents. Therefore, they can operate in the high-frequency range (up to several million cycles). Moreover, ferrites can be easily machined and are cheap to produce.

Just like any other magnetic material, ferrites have a loop-like characteristic of magnetic induction changes (the number of magnetic lines of force per 1 cm$^2$) depending on the field ampere-turns (*aw*).

These important properties of the ferrites make them extremely convenient in the design of complex machine memory systems numbering some hundred thousands or millions of storage elements.

Fig. 11 shows the key diagram of a storage element employing a ferrite core (*a*) and a ferrite-loop characteristic (*b*). Permanent magnets *c* are given for the sake of comparison.

The ferrite core $M$ has three windings. Assume that this core initially was in position 0 (point $B_r$ in Fig. 11*b*). On the arrival of an electric pulse $+aW_{in}$ at the input winding $W_{in}$, core $M$ will reverse its magnetic polarity along the right-hand branch of the characteristic and will shift from point $-B_r$ into the state determined by point $+B_{max}$. After the pulse disappears the core passes into state 1 determined by point $+B_r$, and remains in this state.

The process of the passing of the ferrite core from one state into the other can be explained with the example of a permanent magnet. Assume that input winding $W_{in}$ is wound round the permanent magnet shown in Fig. 11*c*. Let state 0 correspond to the direction of the magnetic lines of force from left to right as shown by arrows on the permanent magnet on the extreme left in Fig. 11*c*, and state 1 to the direction of the magnetic lines of force from right to left (Fig. 11*c* on the right).

As the pulse of definite polarity arrives at the permanent magnet input winding $W_{in}$ a reverse magnetic field is creat-

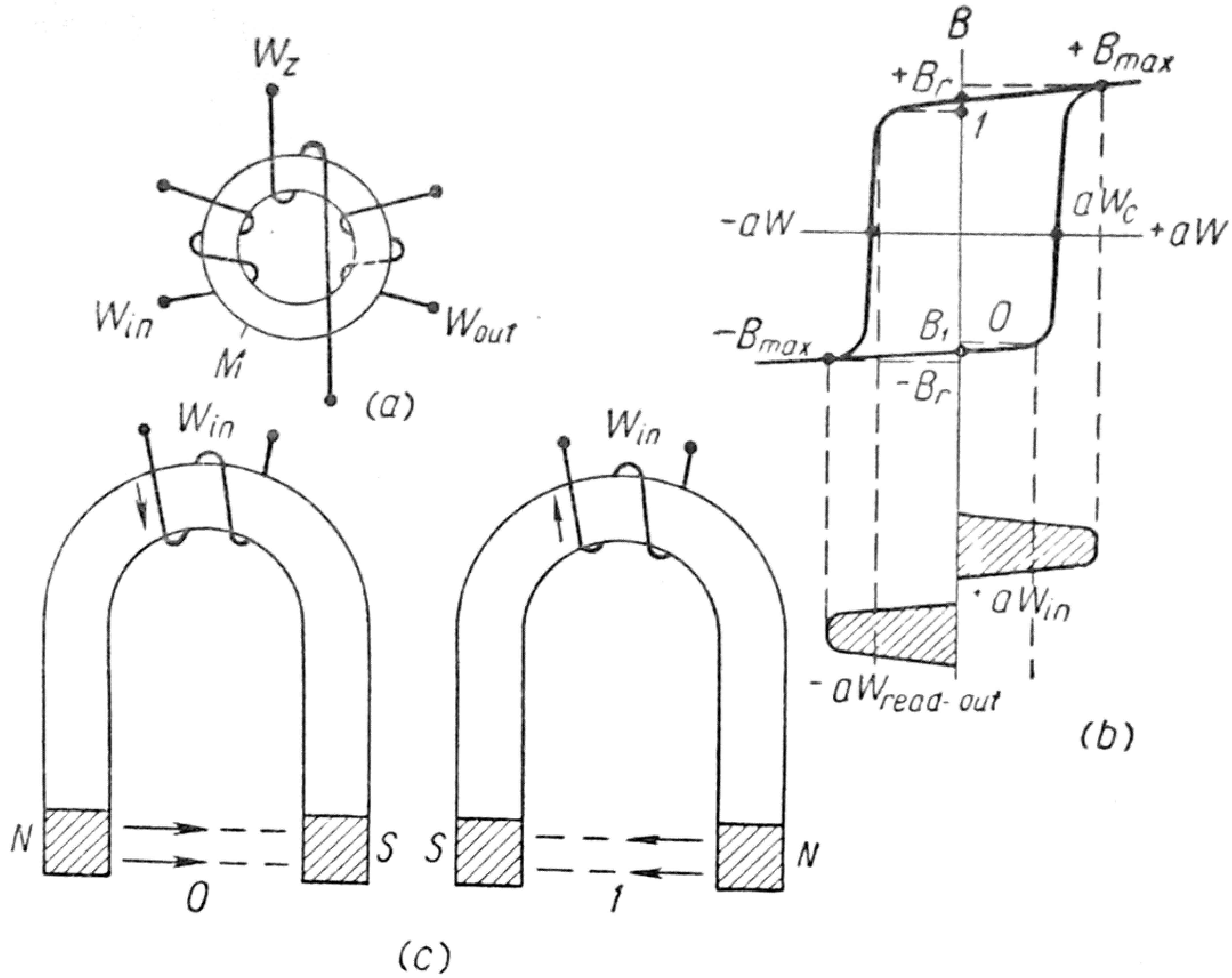



*Fig. 11.* Illustration of the operation of the magnetic volatile memory elements

*a*—ferrite core *M* and windings; *b*—hysteresis loop of the elements; *B*—permanent horseshoe magnets, *aw*—ampere-turn field; *c*—constant horseshoe magnets; *N* and *S*—north and south poles, $W_{in}$—magnetic polarity reversing winding

ed under the action of which elementary magnets of the permanent magnet turn around and orientate themselves in the direction of the applied field. After the pulse ceases the elementary magnets retain their orientation and the poles of the permanent magnet change; the field (i.e., the lines of force) is orientated from right to left. The permanent magnet has "memorised" the signal. Approximately similar processes take place in the ferrite core.

Assume that the state of core $M$ determined by point $-B_r$ corresponds to the permanent magnet lines of force directed from left to right, and the state determined by point $+B_r$ corresponds to those from right to left (see Fig. 11*b*).

Under the action of the positive pulse ($+aw_{in}$) the ferrite elementary magnets orientate in the direction of the applied field and the element "memorises" the signal. The orientation of domains is retained after the input signal disappears.

Now if we feed pulse — $aw_{read\text{-}out}$ into the read-out winding $W_z$ core $M$ will pass under the action of this pulse from state 1 to stage 0 along the left branch of the characteristic (Fig. 11*b*). The induction will change from $+B_r$ to $-B_r$ and the core will remain in state 0.

With the change in the magnetic induction an emf directly proportional to the rate of change is induced in the windings.

The electric pulse appearing in the output winding $W_{out}$ with the induction change from $+B_r$ to $-B_r$ (read-out) carries information to the outer circuit.

The core polarity reverses from 0 to 1 or back again along the entire hysteresis loop. During the reversal the core first assumes the state determined by point $+B_{max}$ or $-B_{max}$ and then, as the pulse ceases, changes to a state determined by point $+B_r$ (1) or $-B_r$ (0). The loop is considered to be ideally rectangular if the value of the maximum induction $B_{max}$ is equal to the value of the residual induction.

Under normal operating conditions it is impossible to achieve an ideally rectangular loop. The quality of the ferrites is determined by the coefficient of the loop rectangularity, i.e., by the ratio $B_r/B_{max}$. Ferrites possess a relatively high coefficient of rectangularity, sometimes as high as 0.85-0.95.

## Magnetic Volatile Memory

A magnetic volatile memory device *MVM* is used for storing information. Bi-polar current pulses created by pulse current transformers of the address system are used for recording and reading out the information.

The number of cores arranged along bar $Z$ (Fig. 12), i.e., in one memory cell, depends on the number of single pulses in the recorded information, i.e., on discharges (the figure

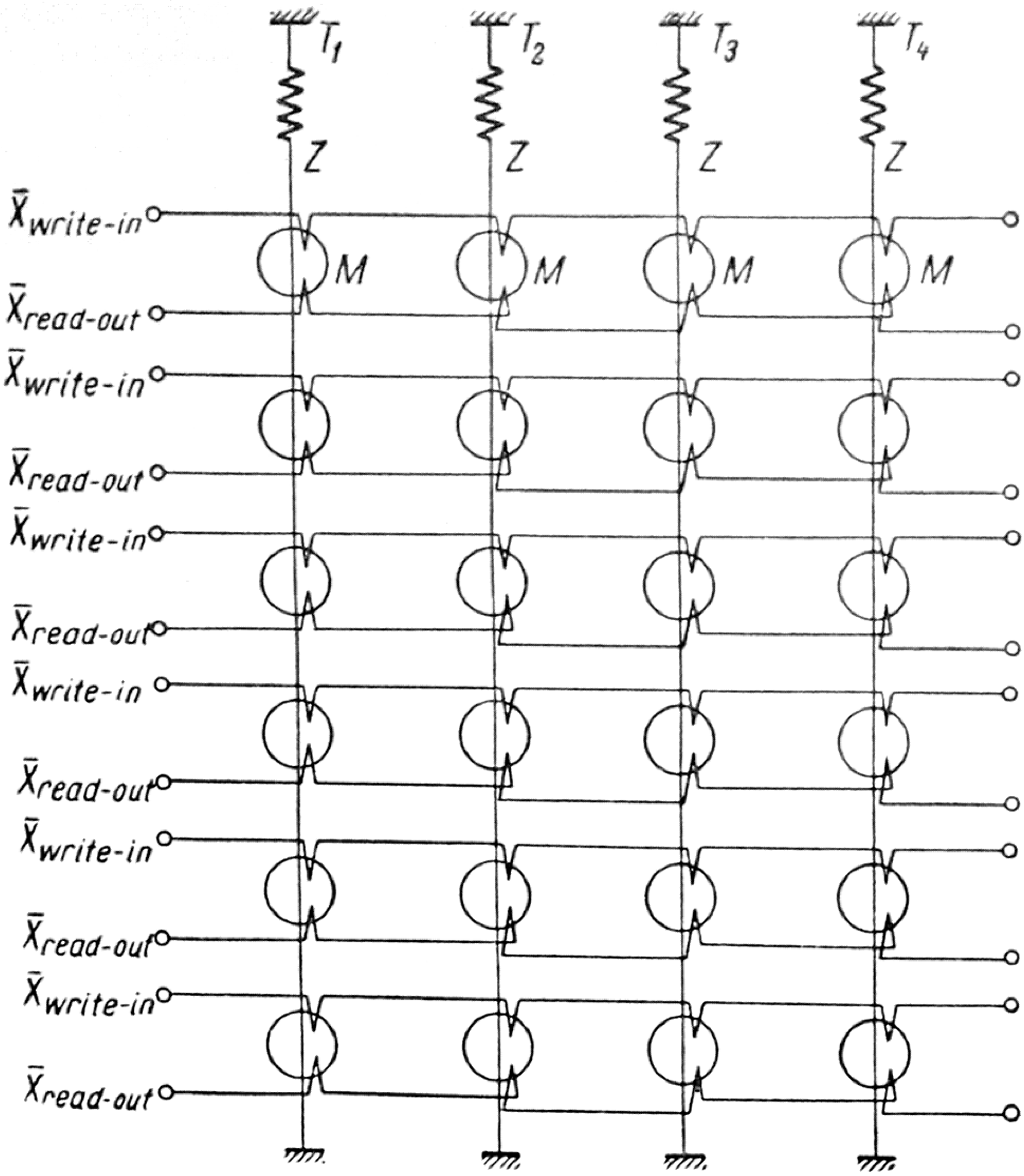



*Fig. 12.* Connection diagram of windings in one cassette of the magnetic volatile memory

$\bar{Z}$—address bars; $T$—address system transformer windings; $M$—magnetic cores $\bar{X}_{write\text{-}in}$—information recording bars; $\bar{X}_{read\text{-}out}$—information read-out bars

shows six discharges). The number of cells depends on the required capacity of the memory. Shown in the figure is the cassette of our cells, therefore, four numbers of six bits each can be written in in one such cassette or read out.

In this case each memory cell is represented by one bar $\bar{Z}$ with memory elements $M$. In practice 20, 40, 80 and more cores can be arranged along one bar, and the number of bars along the coordinate $X$ may be 16, 32, 64, etc. If the

capacity of the device is still insufficient one more coordinate $Y$ can be introduced, i.e., several cassettes are connected into one system.

Each core has three windings: $\overline{X}_{read\text{-}out}$ for reading out signals, $\overline{X}_{write\text{-}in}$ for recording signals and $\overline{Z}$ for establishing the recording and reading out address, i.e., for selecting one number out of many.

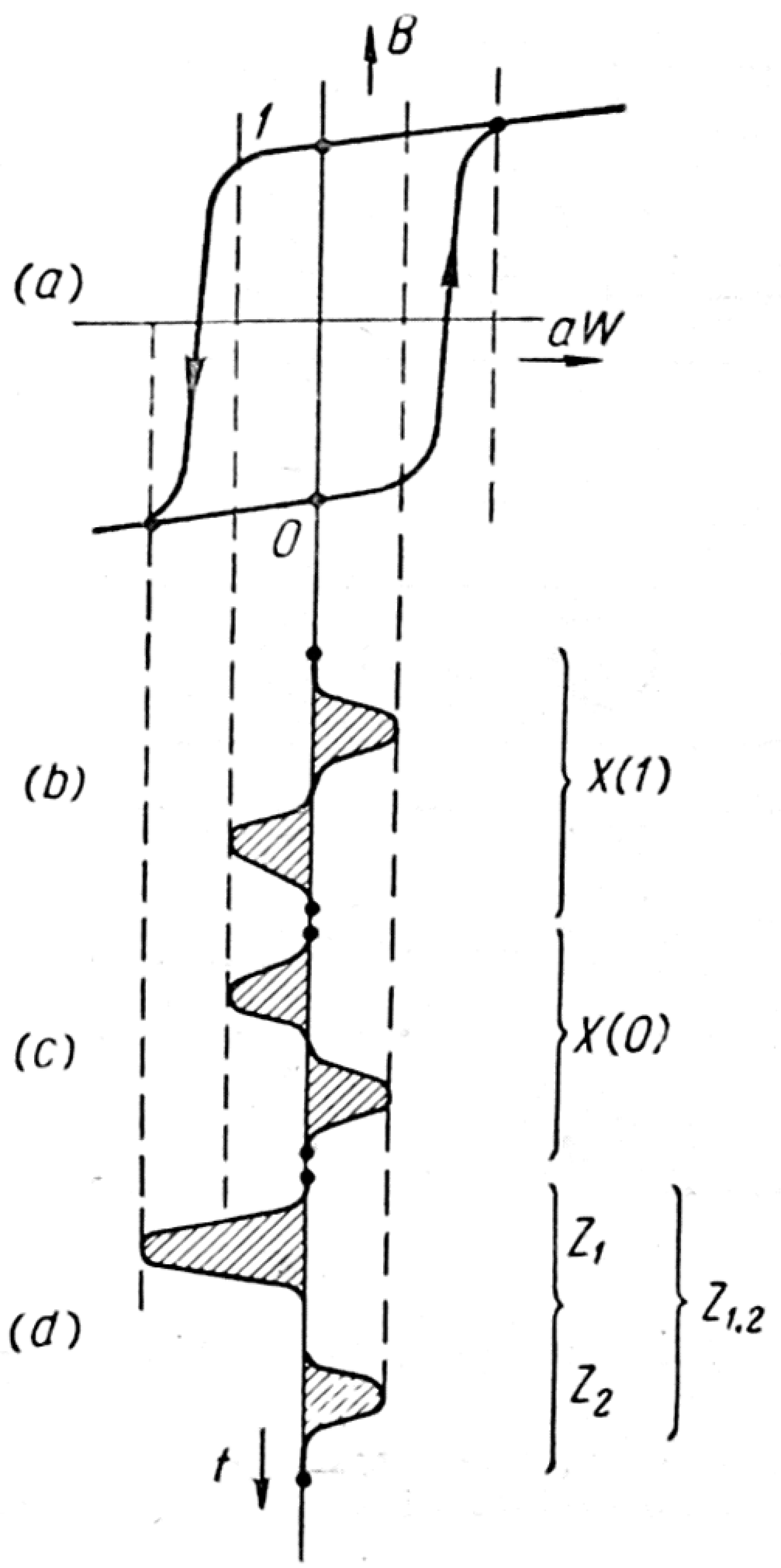



*Fig. 13.* Hysteresis loop of the magnetic memory element (*a*) and the ampere-turn diagram (*b*, *c*, *d*) acting in bar $X$ (0) and unit $X$ (1) are recorded in address bar $Z$.

The first ampere-turns current half-wave coincides in time with the second half-wave in bar Z (with $Z_2$). Half-wave $Z_2$ reads out the information

The first half-wave $Z_1$ of the bi-polar current pulse $Z_{1,2}$ (Fig. 13) arriving from the address system pulse transformers $T_1$, $T_2$, $T_3$, $T_4$ is used for reading out the recorded information. The pulse arrives only to one bar $Z$, i.e., only to those cores from which information is to be read out. The read-out pulse does not arrive at other cores and therefore they retain their information.

The read-out pulse value does not depend on the write-in pulse. Therefore the rate of reading out can be intensified by considerably increasing the read-out pulse current amplitude. After the arrival of the read-out pulse the induction value for all the cores of the given memory cell will be negative (0).

Information is recorded on the selected bar under the action of the second half-wave pulse $Z_2$ of the ampere-turns $Z_{1,2}$ summed up with the write-in ampere-turns.

To record 1 a write-in pulse $X$ (1) should be fed (Fig. 13*b*). The ampere-turns of the write-in current and of the second

half-wave of the current $Z_{1,2}$ are added and the sum is obtained. Under the effect of these ampere-turns the induction changes from 0 to 1, i.e., the unit is recorded.

To record 0, another write-in current pulse $X(0)$ should be applied (Fig. 13*c*). In this case the recording current ampere-turns and those of the second half-wave current $Z_{1,2}$ oppose each other and their sum equals their difference. Under the effect of these ampere-turns only a slight induction change takes place along the bottom branch of the hysteresis loop, and after the pulse ceases value $B$ returns to 0.

Bi-polar write-in currents flowing in windings $X$ act on all the cores of the memory device. In value these currents comprise approximately one-fifth of the sum value of the write-in current (1) and therefore cannot distort information recorded in the cores of other cells.

In practice two cores are used to memorise one bit of information; one for recording information pertaining to 1 and the other one pertaining to 0. Regardless of the code of the recorded number one and the same number of cores determined by a number of bits changes its polarity along the full loop. A circuit of this kind ensures constant loading of the address system transformers. Due to the opposite connection of the read-out winding employing a core, the pair output signals denoting 1 and 0 are of different polarity. Hence the interference effect can be eliminated.

A magnetic memory can be designed not only as a system of cassettes with cores mounted on wire but also as ferrite plates with holes whose number corresponds to the number of cores (256 or 512). In this case the overall dimensions of the entire system are considerably reduced, while the construction and wiring of the device are simplified.

The use of multi-sectional magnetic circuits in the volatile magnetic memory is highly desirable since information is not destroyed in these circuits in the read-out process.

For long storage of the recorded information, memory cores can be made with two mutually perpendicular holes. In this case the strength of current flowing in the bar of the second hole does not change the residual magnetic induction created by the write-in current flowing via bar of the first hole.

For this purpose the second bar passes through radial holes perpendicular to the main hole of the toroid. Information is recorded by the method described above with the help of two currents flowing over bars passing through the core main hole.

Information is read out only by current which is branched off in parallel via bar passing through the radial holes of all the memory cores.

*Non-linear Dielectrics.* Among dielectrics there is a group of materials called segnet-electrics which to a certain degree have similar dielectric properties as ferromagnetic materials. They are: barium, titanate, triglycinsulfatehexahydrate, etc.

Changes in the electric field intensity are followed by the processes similar to those of orientation of domains in ferromagnetic materials with the change of the magnetic field intensity.

The loop characteristic $Q=f(u)$ (where $Q$ is the charge across the capacitor plates, and $u$ is the applied voltage) of such capacitors can be used in creating memory elements with the help of non-linear dielectrics.

Logical machines are intended to have a rather extensive volatile machine memory. It can employ nothing but memory cores since information recording and reading out is controlled by electric pulses.

## Capacitive Volatile Memory

A capacitive device (Fig. 14) based on the use of non-linear capacitors with loop characteristic $Q=f(u)$, similar to curve $B=f(aw)$ (Fig. 15), can be employed as a volatile memory. The principle of operation of the capacitive memory is similar to that of the magnetic memory.

All elementary capacitances have a practically rectangular loop characteristic $Q=f(u)$ (Fig. 15*a*). When the outer electric field is absent, they all remain, after some charging and discharging, in the state shown in Fig. 15*a* by numbers 1 and 0. This means that the capacitances in this state have either positive or negative charge $Q$.

Information is read out when one common negative volt-

age pulse is fed to all the capacitors arranged along one vertical bar $Z$ (Fig. 14). The process is as follows: positively charged capacitors (1 in Fig. 15*a*) recharge and become negative (points 0 in Fig. 15*a*) while those negatively charged retain their charge under the action of the negative voltage pulse.

In the first case, during recharging, voltage pulses are induced across output bars $B$ (Fig. 14) due to the change of charge with time. These pulses indicate that the capacitors were positively charged, i.e., that they were in state 1. The absence of a pulse at the output bar during read-out means that the capacitors were negatively charged, i.e., that they were in state 0.

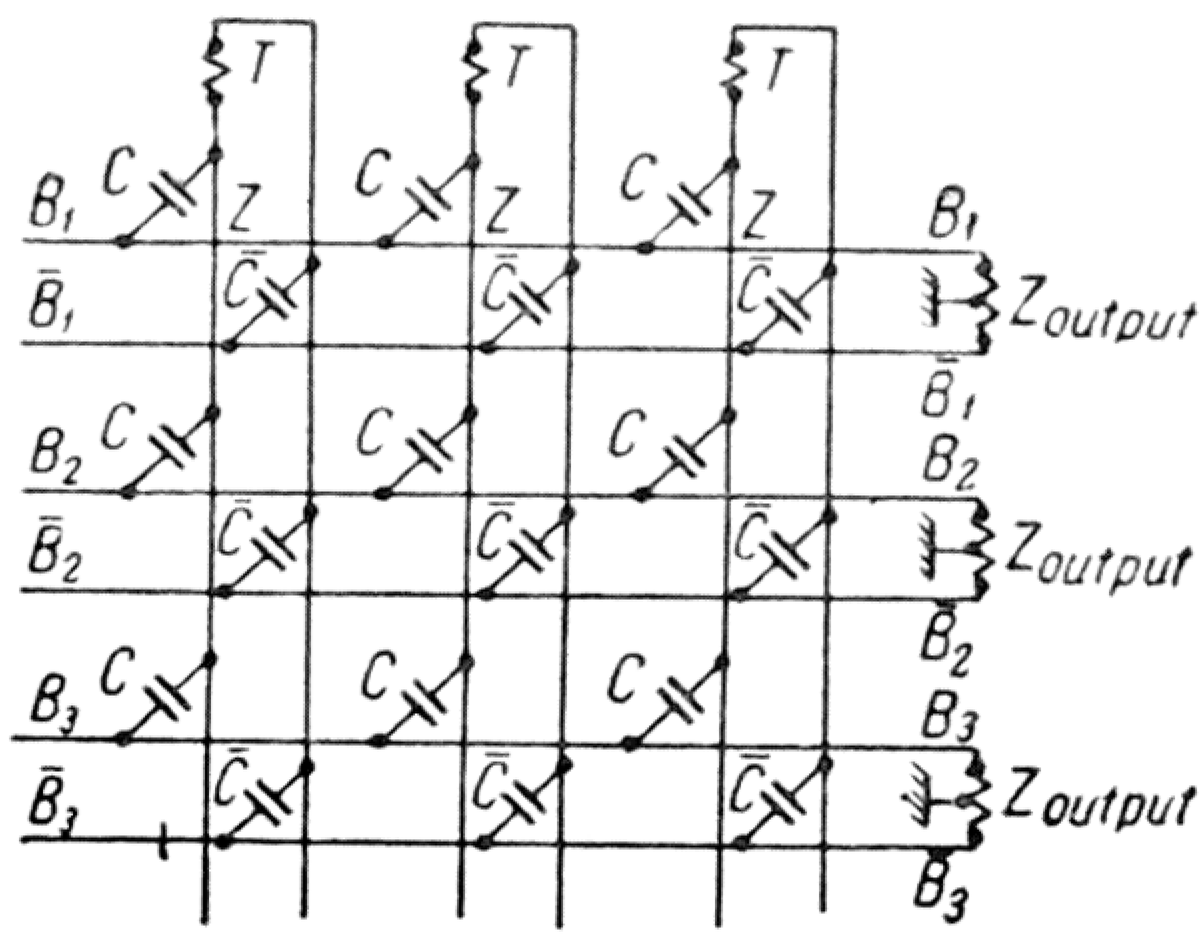



*Fig. 14.* Diagram of a volatile capacitive memory with doubled number of bars and capacitors to improve reliability and noiseproof features

Information is read out with the help of one pulse from all the capacitors connected to the selected vertical bar.

Only one voltage pulse $U_{z1}$ (Fig. 15*b*) is used to discharge elementary capacitances, i.e., to read out information. The pulse is not limited in value by $U_o$. Hence the current value obtained in reading out information can be steeply increased.

The difference of the two voltage pulses $U_{z_2}$ and $U_x$ (Fig. 15*b*) is used for recording information in the capacitors of the given bar.

Voltage $U_{z2}$ is always present after the read-out pulse $U_{z_1}$ (see Figs 15*b* and *c*). Pulses $U_x$ are fed to bars $B_1$, $B_2$..... When the capacitors are charged, i.e., when information is recorded, the write-in voltage value $U_x$ in the bar Y is added to pulse $U_{z_2}$ and comprises approximately only 0.25 to 0.3 of the value of $U_o$. To record 1

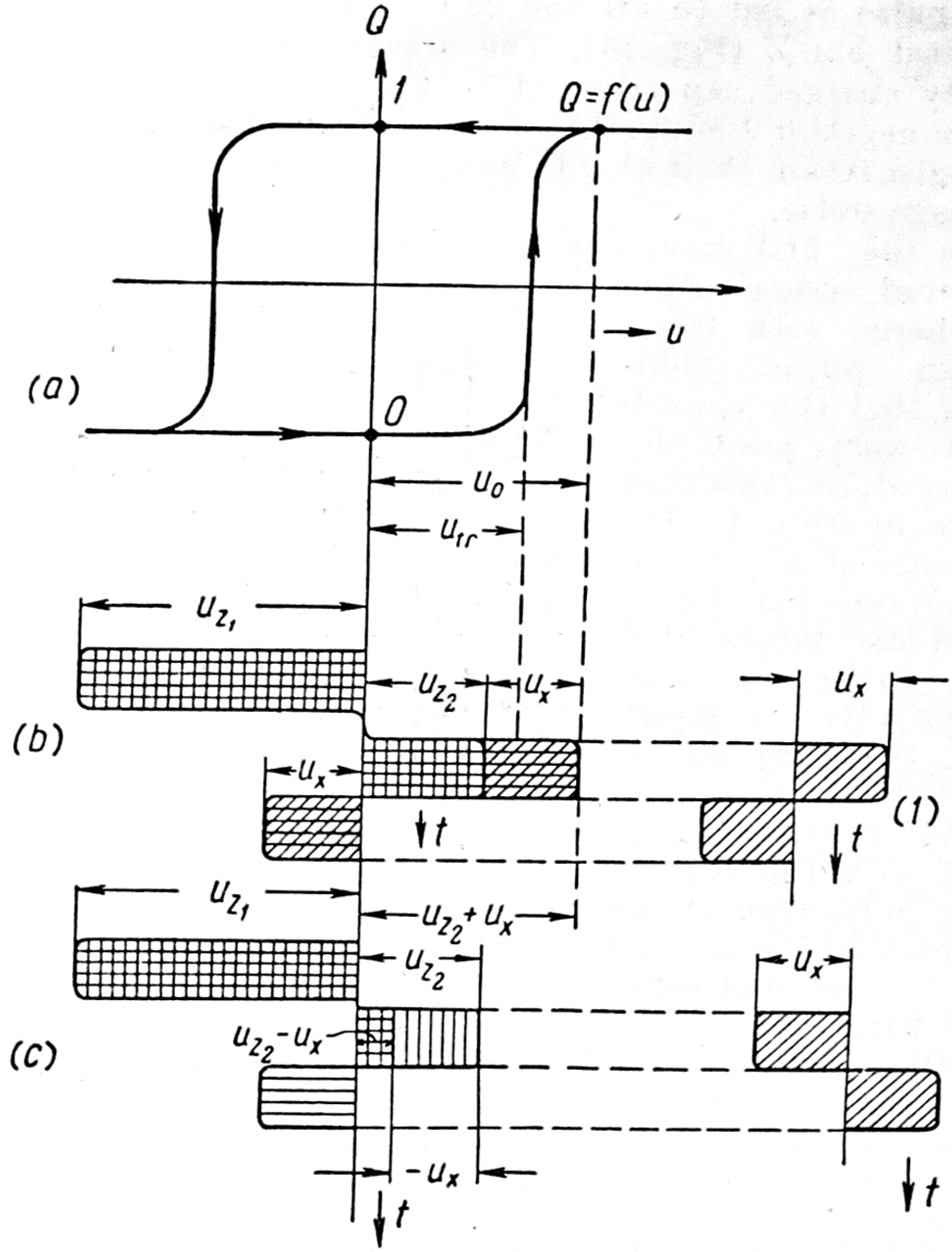



*Fig. 15*. Hysteresis loop $Q=f(u)$ of the non-linear write-in element of the volatile memory and the diagram of values $U_z$ and $U_x$ acting upon the element along bars $Z$ and $X$

the write-in pulse $U_x$ should coincide in sign and phase with pulse $U_{z_2}$ (see Fig. 15*b*).

To record 0 the pulse should be opposite in sign to pulse $U_{z_2}$ (see Fig. 15*c*).

When recording 1 the resultant pulse $U_{z_2}+U_x=U(1)$ will be greater than $U_o$, the value required for recharging the capacitor, and when 0 is recorded the resultant pulse $U_{z_2}-U_x=U(0)$ will be below the threshold value $U_{tr}$ which, as can be seen from Fig. 15*a* is insufficient for recharging the capacitor with rectangular characteristic $Q=f(U)$.

The ratio between $U(1)$ and $U(0)$ can be greater than 3. Thus the characteristic need not be strictly rectangular any longer.

Interference can be cut down by employing double capacitors, i.e., by using a pair of capacitors to write in one bit of information. In this way one of the two capacitors is always recharged ($C$ and $\bar{C}$).

If you want to record 1 the top capacitor of the pair ($C$) is charged, and to record 0 the bottom capacitor $\bar{C}$ is charged.

During the reading out pulse $U_{z_1}$ always discharges one of the pair of capacitors and the discharge current always creates a pulse at the output bars $B$, the sign of this pulse (i.e., its polarity) determining 1 or 0.

This system is quite stable against interferences and keeps the winding $T$ under constant load regardless of the code of the parallel information read out.

The capacitive memory using non-linear capacitors can be very compact in design, made of plates (cassettes) metallised on both sides.

Capacitive memory devices are as yet in the development stage. Most of the modern systems of this kind employ ferrite cores and plates. Large capacity information machines require a memory for a hundred million signs.

In one information machine the capacity of all the memory units approaches 100 thousand cells.

Memory units used today contain up to 32,763 cells, 42 bits each, with an access time of approximately 10 mcsec.

A volatile memory is dozens and even hundreds of times more expensive than a long-time memory since it requires high-speed recording and erasing systems which are unnecessary in the long-time memory, because information is stored in it without losing its importance for many years.

# Machine Memory Address Systems

Letters, words, figures, formulas, diagrams, etc., are recorded in a machine long-time or volatile memory just as they are written down on the pages of any book. Pages of a long-time memory comprise units which can be regarded as books. Units are shelved just as books are in a library.

Electric circuits serve for sending control address signals to retrieve any element of the stored information (a separate sentence, diagram, formula, etc.).

Just as elements of information in a book have their own address (the name of the book, page number, line) in our system each element of information has its own address (a number) in the common address system. Furthermore, just as subscribers of an automatic office can be called by dialing their number, these elements of information too can be connected by the switchboard (called up) to the computer or to any other unit of the information and logical machine.

## Multi-dimension Address Systems

Machine memory cells operate (read out or record information) under the action of the current created in their system.

An address system is an electric circuit similar to some multi-dimension grid or mesh the nodes of which comprise the memory cell. Address currents—the signals of the bit code denoting the number of the selected cell—serve as addresses.

An address can be expressed by one figure when all the cells are numbered in succession from first to last, as for example from 1 to 1,000,000. In this case the address system can be represented as uni-coordinate.

Shown in Fig. 16 is the uni-coordinate circuit (chain). The circuit has a number of nodes arranged in a straight line one after the other. Black rectangles are memory cells, which are connected to the nodes. If we take the first node

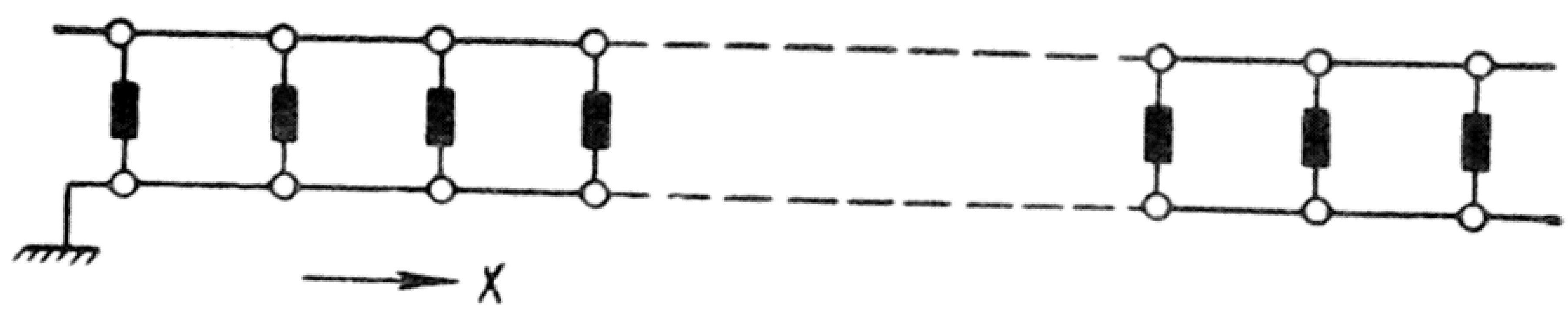



*Fig. 16.* Diagram of a uni-coordinate address system

on the right to begin reading (0) and agree that any arbitrary number, for example 10, will denote the unit then we can express all other elements of the grid by decimals (coordinate $X$). If we assume the first node is 2, then any cell in this row can be expressed by binary numbers. An address system for a uni-coordinate retrieval of information from memory cells is a conventional decoder.

A diagram of a magnetic decoder is shown in Fig. 17*b* to illustrate the process of selection of memory cells. With the help of the decoder one binary number ($n$ signals of binary code) excites one of 2 decoder output elements ($n$ is taken equal to 3 and $2^3=8$). Uni-coordinate address systems of this kind have 32, 64 and up to 256 cells.

As was already shown, the cell address (bar $Z$) should be given at the decoder input simultaneously with its direct $K$ and reverse $\bar{K}$ code, while coupling elements between bars $Z$ and $X$ should be set in the reverse order—reverse $\bar{C}$ and direct $C$ code (see Fig. 3). In this case the required cell, ordered by the address code bar $Z$ will not be excited. But the problem is to feed the pulse to the selected cell of the bar $Z$.

The additional keys *NOT* used at the bar $Z$ output of the decoder serve as inverters. Such a *key* or an element of *dissimilarity* excites the following pattern of logical operations as regards the two code signals.

| | At output 1 | | At output 2 | | At output 3 |
|---|---|---|---|---|---|
| Signals | 1 | + | 1 | = | 0 |
| „ | 1 | + | 0 | = | 1 |
| „ | 0 | + | 1 | = | 1 |
| „ | 0 | + | 0 | = | 0 |

This operation in the algebra of logic is called the *negation of synonimity* (excluding "or"). An utterance is true in the case, and only in the case, when only one of several utterances is true.

If an additional cycle-time is used during decoding to feed the second pulse, then a simple magnetic core can be used as key *NOT*.

Connect these cores to all bars $Z$. The cores are so selected that they are easily saturated and lose their magnetic properties straight after one signal from bar $X$ or $\bar{X}$. In this case only one of the cores through whose windings no current flows retains its magnetic properties. If now a pulse is fed via the winding passing through all the cores, power will pass only through one of them, through a non-saturated one. In the given case it will be $NOT_6$, with the code address 101.

Thus the conclusion can be drawn that to feed power to one of the cells in the uni-coordinate address system, the following operations should be performed in succession. The address code given in the form of one bit should be inverted and the reverse code obtained. The direct and reverse code signals should be fed to bars $X$ and $\bar{X}$ of the decoder circuit and then should transfer power via $n$ keys of the *NOT* type of the $m$ memory cells with the help of a powerful pulse. The efficiency of this system is very low.

Shown in Fig. 17 is the eight-position magnetic decoder circuit. It comprises eight transformers, the transformation ratio of which changes under the effect of the code pulses. All the transformers have one common primary $W_0$ through which the primary current passes simultaneously from one current source $G$. The value of the output signal of each transformer depends on the magnetic permeability of its magnetic core $M$.

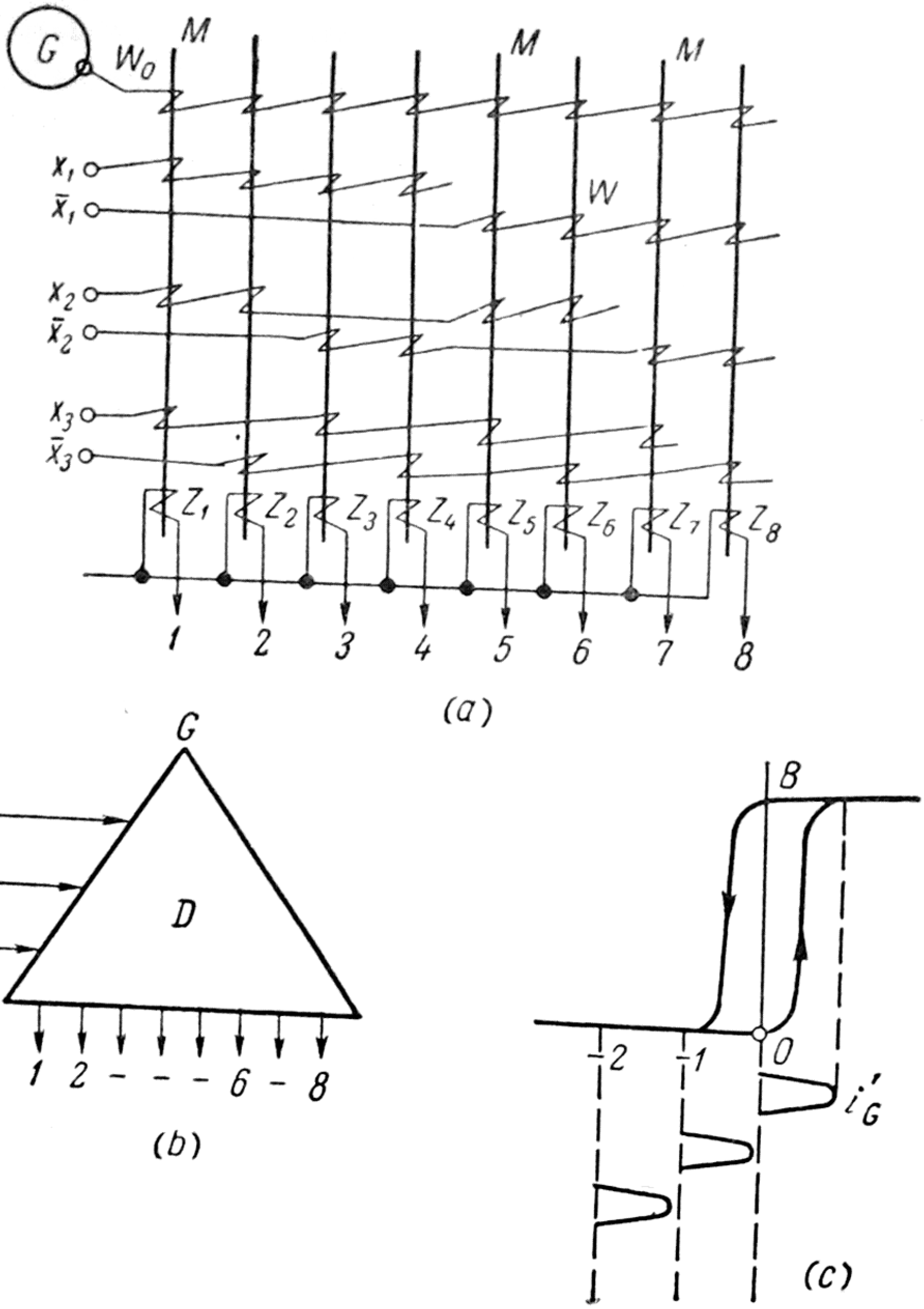



*Fig. 17.* Magnetic decoder

a—key diagram (M—magnetic cores, side view); windings X and $\overline{X}$ of the address code signal currents; winding $W_0$ for read-out pulse current from generator G; b—decoder designation; c—hysteresis loop of the decoder magnetic element (B—induction, $i_G$ —generator G pulse current; 0, -1, -2—various positions of the initial point on the hysteresis loop when magnetising field (0) is absent and when present from windings X(-1, -2)

The value of the magnetic permeability of core $M$ changes depending on the currents in the three pairs of horizontal input bars $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_3$. These "code currents" are set up in the bars by the given binary code. When the code contains figure 1, the pulse is fed via the bar $X_k$ and when it contains 0, the pulse is fed to bar $\bar{X}_k$. These currents saturate some magnetic core $M$ of the system. At any three-digit bit seven cores will be saturated and one (out of eight) will not be. Control current will not flow via the bars of this core.

The values of these signal pulses are selected so that the magnetic cores are saturated and lose their property to conduct power from the common primary $W_0$ to the secondaries $Z$ placed separately in each core.

Given is the code 000. Control currents are flowing via three horizontal bars $\bar{X}_1$, $\bar{X}_2$ and $\bar{X}_3$ and only the first left-hand core is not under the effect of these currents. Its magnetic permeability is very great while that of the rest of the seven cores is rather insignificant due to the effect of the magnetisation currents. Hence the signals which appear at the output windings $Z$ of these seven transformers are rather weak as compared with the output signal of the first transformer.

When another combination of the three-digit code pulse arrives, the corresponding output winding of the decoder is excited. For instance code 101 will excite the fifth winding; code 011, the third winding.

For simplicity the decoder circuits will be depicted as triangles (Fig. 17*b*), having $n$ inputs for the code signals and $2^n$ output circuits with a common source $G$ connected to its apex.

It is expedient to use two-coordinate grids for many of the systems. A two-coordinate grid can be made by connecting the nodes of a number of adjacent uni-coordinate chains. Each node in this grid is determined by two numbers (coordinates $X$ and $Y$). Coordinate $X$ determines the node number along the chain, while coordinate $Y$ determines the number of the chain in which there is a node with the necessary memory cell.

The selection of the given memory cell is determined by the functioning of two decoders which excite one bar of

the grid along coordinate $X$ and the other bar along coordinate $Y$ from the keys of the AND type. The significant feature of this key is that a signal appears at its output only when the unit signals arriving at its output coincide in time. This operation corresponds to the function of logical multiplication which with the two input signals can be expressed by the following table:

| Signal at input $A$ | | Signal at input $B$ | | Signal at output $C$ |
|---|---|---|---|---|
| 1 | $\times$ | 1 | = | 1 |
| 1 | $\times$ | 0 | = | 0 |
| 0 | $\times$ | 1 | = | 0 |
| 0 | $\times$ | 0 | = | 0 |

The control signal 1 is fed at the right moment from the control device to the input $B$ of element AND to determine the presence of the code signal 1 or 0 in the arriving information. If signal 1 was at the input $A$, we get 1 at the output, and we get 0 if there was 0 at the input $A$.

With a great number of input signals the key AND should have just as many input circuits and one output circuit, which is excited only with simultaneous excitation (by units) of all the input circuits.

# Number Magnetic Address System

The number magnetic address system is a mesh comprised of ferrite cores and controlled with the help of magnetic decoders.

The two-coordinate address system (Fig. 18) is a mesh comprised of small-diameter ferrite cores at the intersection of vertical (coordinate $Y$) and horizontal (coordinate $X$) address bars.

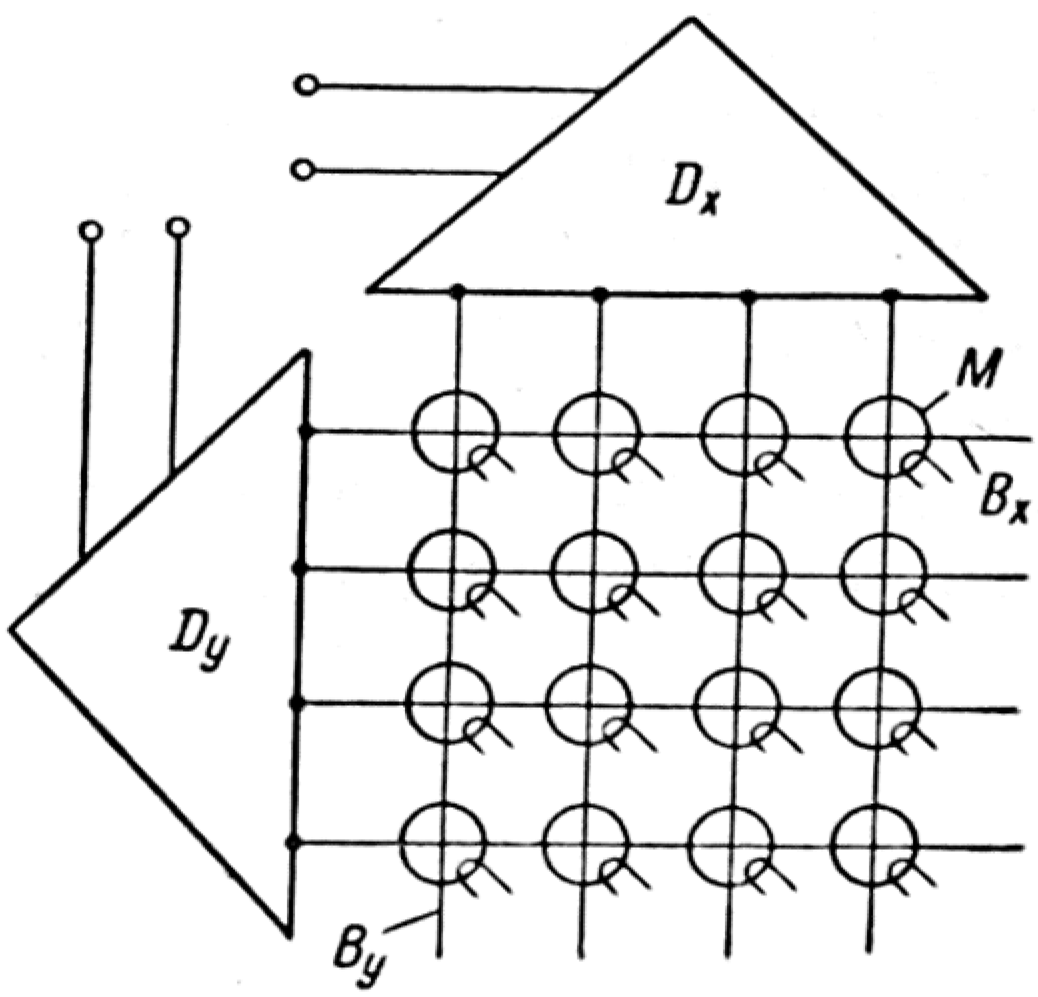



*Fig. 18.* Electrical diagram of a two-coordinate address system:
$Bx$ and $By$—coordinate bars; $Dx$ and $Dy$—decoders; $M$—magnetic cores

Control signals arrive at these bars from two decoders $D_x$ and $D_y$, each of which has 2 inputs and 4 outputs. The address code consisting of 4 binary rows is divided into two parts with two rows each, and arrives at the decoders $D_x$ and $D_y$.

The decoders feed current pulse to one of the vertical ($B_y$) and one of the horizontal ($B_x$) bars of the address grids, consisting of magnetic keys of the type AND...AND. A magnetic key of this type operates and lets the power from the common source through, only in the presence of two currents—current from bar $X$ and current from bar $Y$. Its function, therefore, corresponds to logical multiplication—the function "AND". The current sum (double current) acts upon core $M$ at the intersection of these two bars. The magnetic induction in this core (coordinate transformer)

changes in accordance with the complete hysteresis loop (Fig. 19) and the current pulse $Z_{1,2}$ is induced in its secondary acting on the memory cell and controlling the reading of the information.

Constant biasing ampere-turns $aw_0$ act upon all the cores (Fig. 19). The initial point $0_1$ is set under the effect of the biasing current so that only the sum of two currents ($aw_x$ and $aw_y$ in Fig. 19) from the mesh bars $B_x$ and $B_y$ change the magnetic induction along the complete hysteresis loop.

The current from one bar produces but a slight change in the induction which can be practically compensated for by simple means. Interference created after compensation by the current of one bar is approximately 0.2% of the pulse created by the sum of currents and, therefore, cannot impede normal operation of the device.

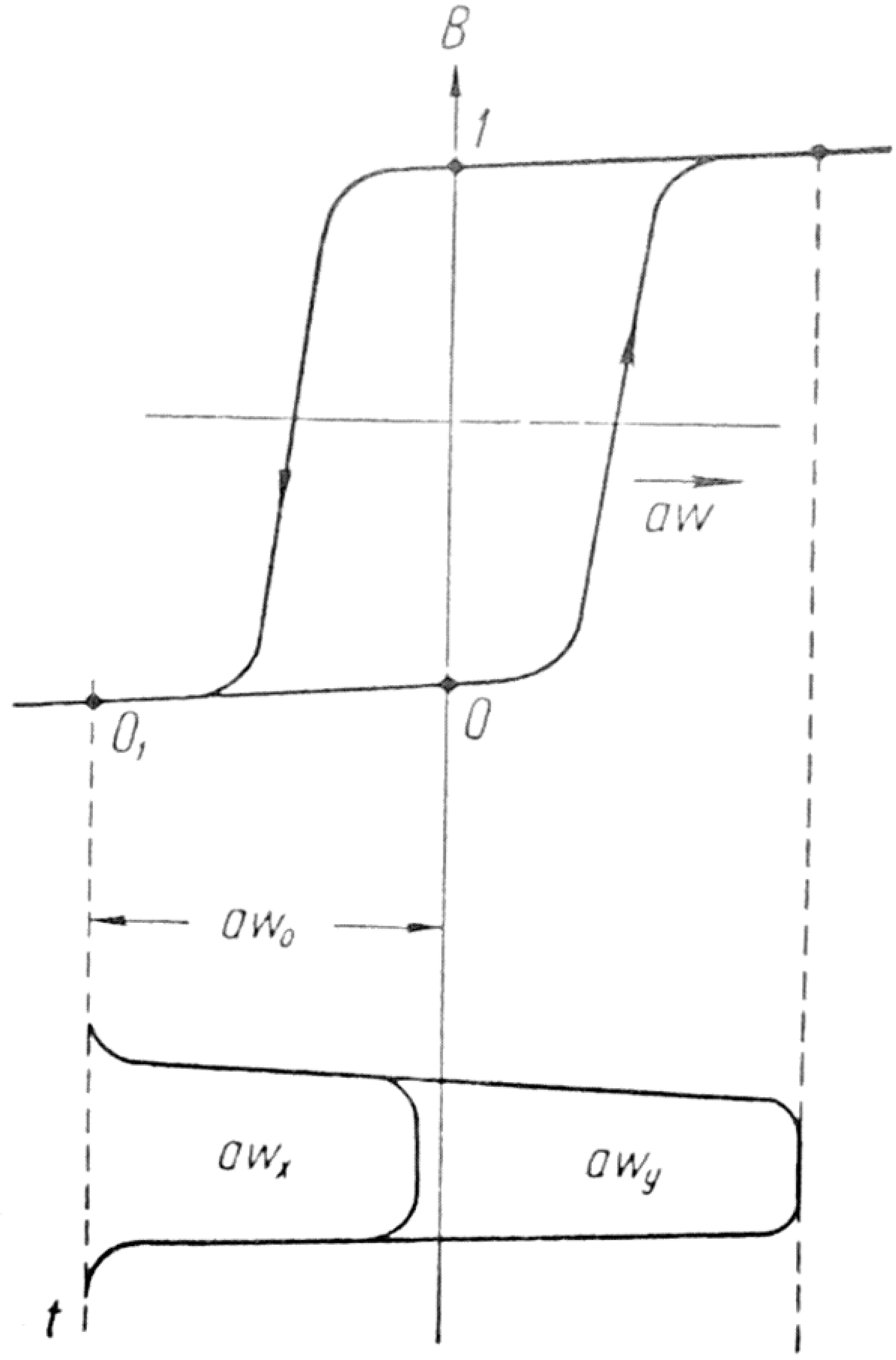


*Fig. 19.* Hysteresis loop of key AND (of a non-linear element) and diagram of values $aw_x$ and $aw_y$ acting upon this element along bars $B_x$ and $B_y$

However, this unilateral current acting upon the magnetic key AND leads in the final analysis to the loss of some of the power and creates a certain interference at the output. In the uni-coordinate system the number of these partially excited keys is equal to the number of cells in the address system. If their number is great then even with insignificant loss of power in each key the efficiency of the uni-coordinate system is very low. Thus, for example, if there are one million cells and only 5% of the power of

one fully excited key is spent on each partially excited key, then power losses will be 50,000 times greater than the useful power necessary for the excitation of one selected cell ($10^6$ keys $\times 5 \times 10^{-2} = 5 \times 10^4$).

In the two-coordinate system with a million cells the number of partially excited cells will be 2,000 (instead of a million) and the losses will already be 100 times greater than the useful power ($2 \times 10^3$ keys $\times 5 \times 10^{-2} = 10^2$).

In the three-coordinate system, the conditions remaining the same, there will be only 300 partially excited keys ($3\sqrt[3]{10^6}$) and the power losses will be only 15 times greater than the useful power, i.e., its efficiency will be approximately 6%. With a smaller number of partially excited keys general losses decrease correspondingly.

To increase the capacity of the logical machines it is expedient to use a four-coordinate system. With $2^{20} \approx 10^6$ cells the number of partially excited keys will be 128

$$(4\sqrt[4]{2^{20}} = 128)$$

and the efficiency for the case considered will be approximately 15%.

With further increase of the memory capacity, the optimal number of the coordinates of the address system has to be found.

The present-day electronic digital computers with 1,000-4,000 memory cells employ a two-coordinate address mesh. In this case the number of partially excited keys is respectively 64 and 128.

A three-fold increase in the capacity of the memory as compared with the computer memory cells for the introduction of a qualitatively new type of multi-coordinate address system—in particular, four-coordinate.

The number of memory cells in an information machine can reach many millions. In this case multi-coordinate address systems are used.

If we arrange memory cells within a cube, the location of each cell will be determined by the three special coordinates $X$, $Y$ and $Z$. It was illustrated a long time ago that models of "multi-dimension bodies" with a large number

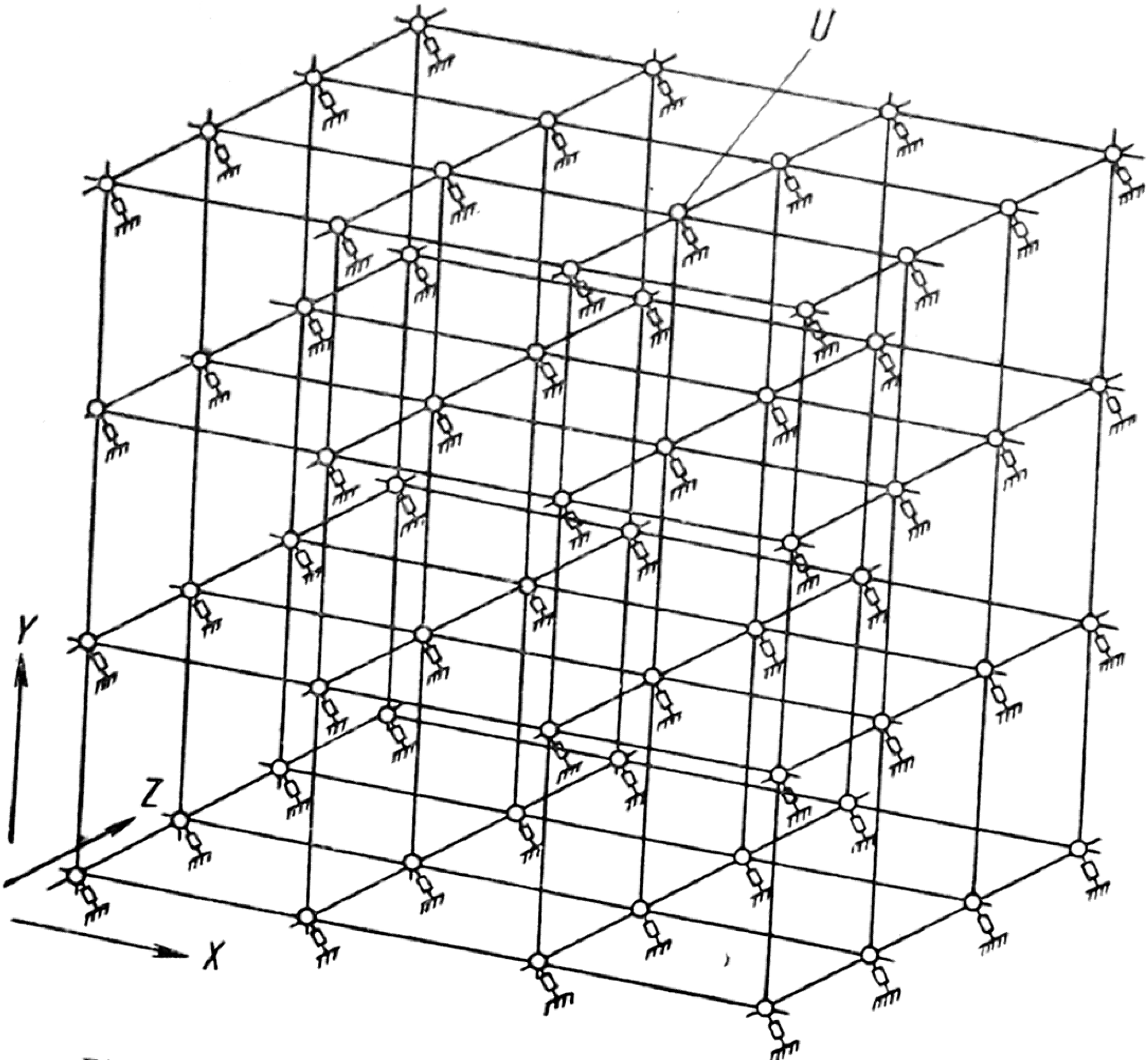



*Fig. 20.* Diagram of a three-coordinate address system

of coordinates can be based on electrical circuit properties. This fact can also be utilised in building multi-coordinate address systems of a machine memory.

A spatial mesh reminding one of a crystal lattice can be built by joining the mesh nodes with the help of coupling elements (Fig. 20). A circle denotes the key AND which induces a memory cell (rectangular) when signals arrive at the key from the coordinate bars.

The frequencies used in the machine memory operation allow us to disregard the spatial dimensions of the arrangement of mesh elements. The elements of the three-dimensional electrical circuit (Fig. 20) can be arranged on a number of planes as is shown in Fig. 21.

6—2072

Both circuits (Figs 20 and 21) are perfectly equivalent from the electrical point of view. Each node in the mesh (Fig. 21) is determined by three numbers—coordinates $X$, $Y$ and $Z$.

An electrical mesh topologically similar to an $n$-dimensional figure can be made based on the three-dimension mesh principle. The location of each node of the multi-dimensional circuit will be determined by $n$-numbers (coordinates). Fig. 22 shows the connection diagram of a four-dimensional mesh. The location of each node is determined by four coordinates—$X$, $Y$, $Z$ and $q$. Three coordinates determine the position of a given node in each "cube" (three-dimensional mesh) and the fourth number, the coordinate $q$, locates the cube in a chain comprised by the three-dimensional meshes (cubes).

If each uni-coordinate decoder has 32 outputs in a four-coordinate address system any memory cell can be selected from a million possible cells ($32^4 = 1048576$).

A four-dimensional mesh consists of a number of three-dimensional meshes linked up in a chain. The chain has a beginning and an end, i.e., the first and the last three-dimensional element in a chain. Such a four-dimensional circuit is developed in one plane (Fig. 23).

In principle, meshes with any number of coordinates can be built. To arrange such a mesh a number of three-dimensional "cubes" should be interconnected to form a circuit or a mesh out of four-dimension circuits can be developed on a plane. The process of making multi-dimensional meshes can be continued.

Such multi-dimensional electrical models were introduced into the theory of electrical modelling of intricate figures in physical processes.

We do not know how the address systems are arranged in the human brain. Reproduction of information from human memory according to the principle of association of ideas can be likened to the operation of the multi-coordinate address system. Addresses in this case will be various combinations of words and notions.

The more words there are in the address, the more accurate is the image created in our memory. If we take the number of words corresponding to the number of coordinates

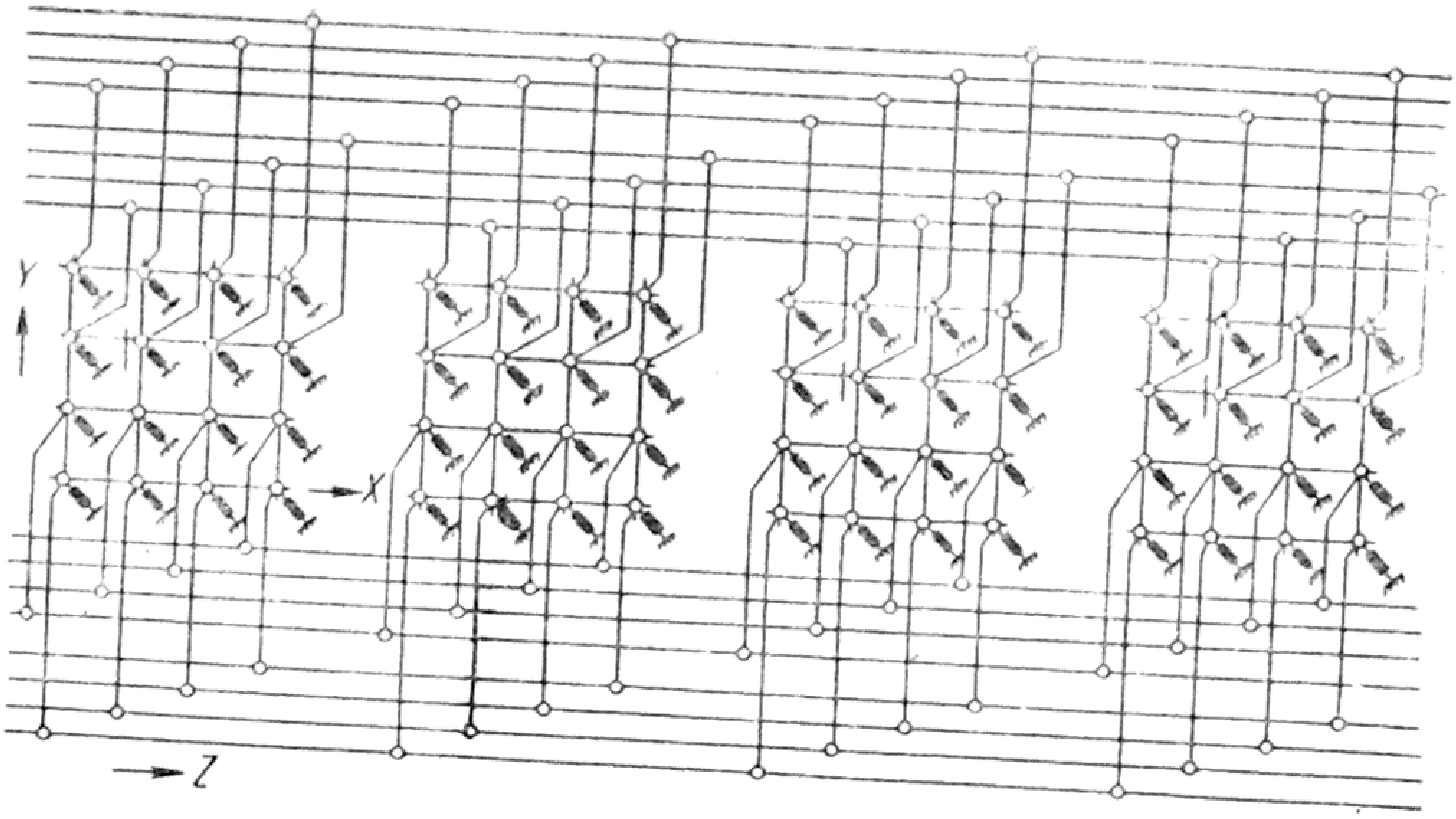



*Fig. 21.* Diagram of a three-address system developed in one plane

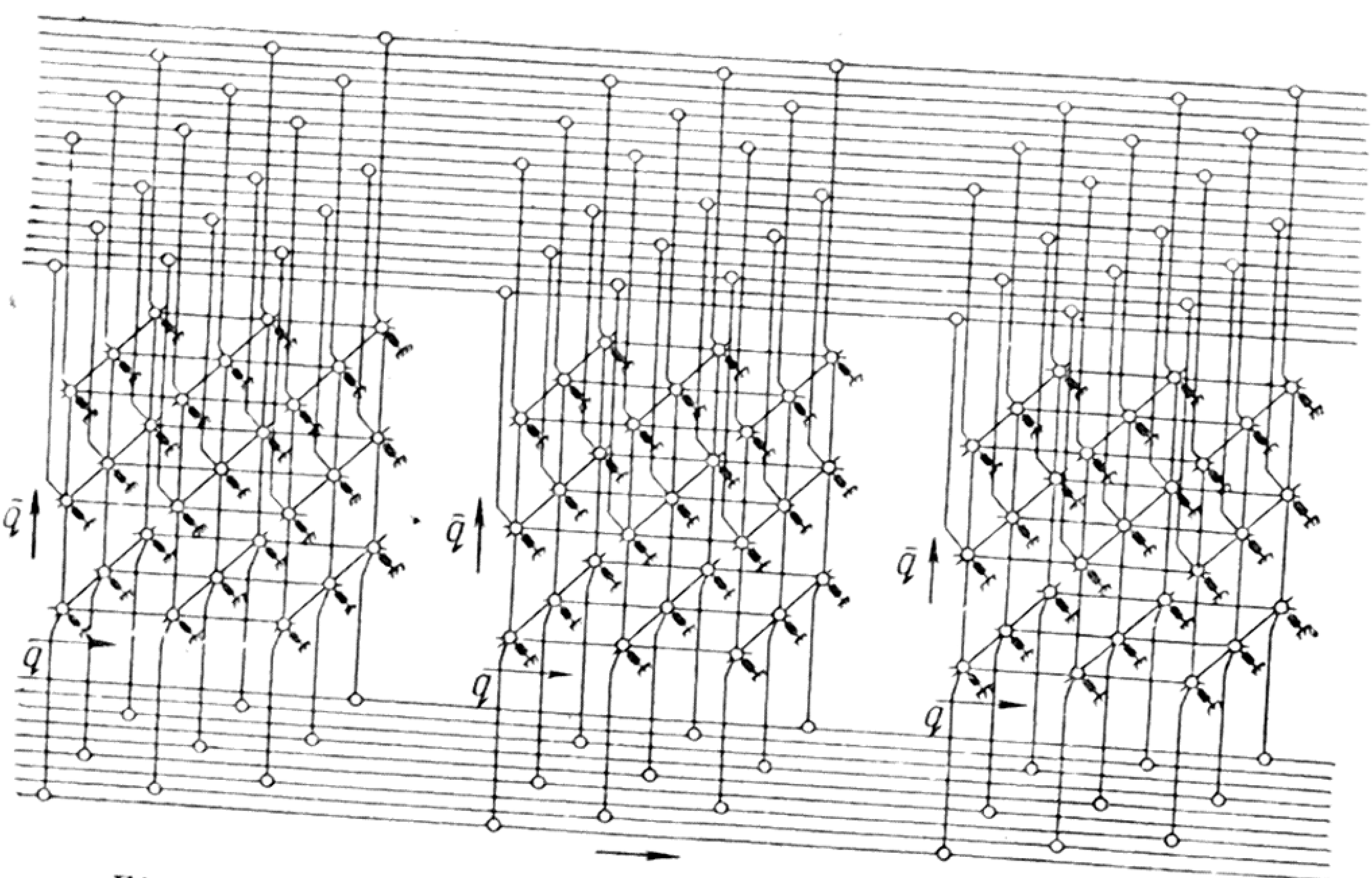



*Fig. 22.* Diagram of a four-coordinate address system

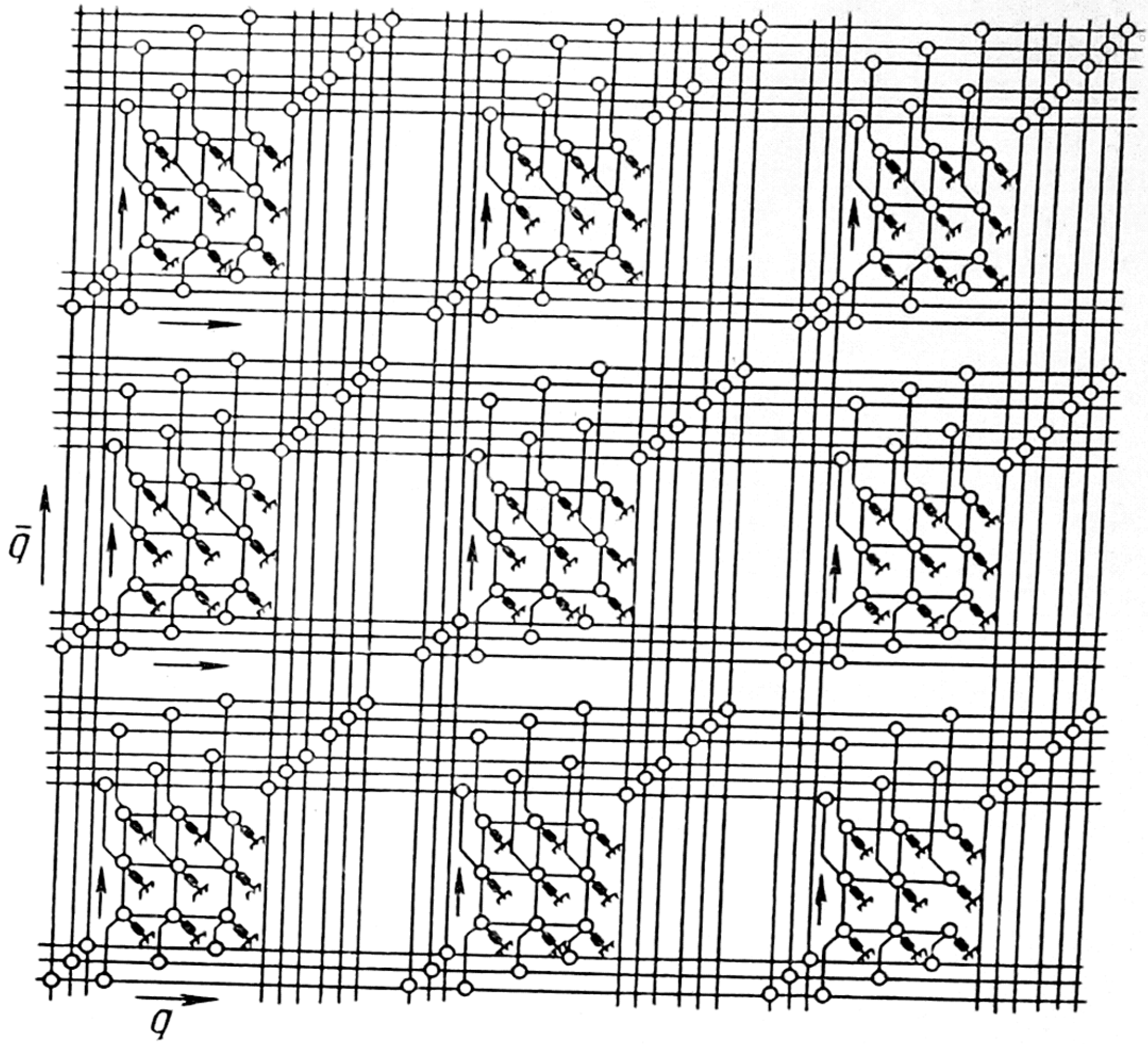



*Fig. 23.* Diagram of a four-coordinate address system developed in one plane

of this original word address system, it can be easily seen that the number of coordinates is very great.

Undoubtedly this system differs from that of the digital address system. Since the addresses are expressed in it by this or that association of ideas (or words), it is only natural to call it an *associative* or *word* address system.

In order to model the process of information retrieval from the total memory, the problem of building a machine associative (or word) address system should be solved. Let us discuss some of the first results of the developments of such a memory.

Associative memory is a further development of the decoder circuit described above. The number of bits in the address expresses a certain random combination (association) of properties which however have no strict correspondence with the number of output bars $Z$ or with the attributes (i.e., the memory cells). In the decoder these relations are determined by the equation $m=2^n$ where $n$ is the number of the code address bits and $m$ is the number of output bars.

In the associative unit the addresses are often arranged on a plane as a two-coordinate field of properties (see Fig. 24b). Such a field can contain up to a thousand attributes. In the bit system the number of all possible combinations in this case is practically limitless ($2^{1000}\approx 10^{300}$), while the

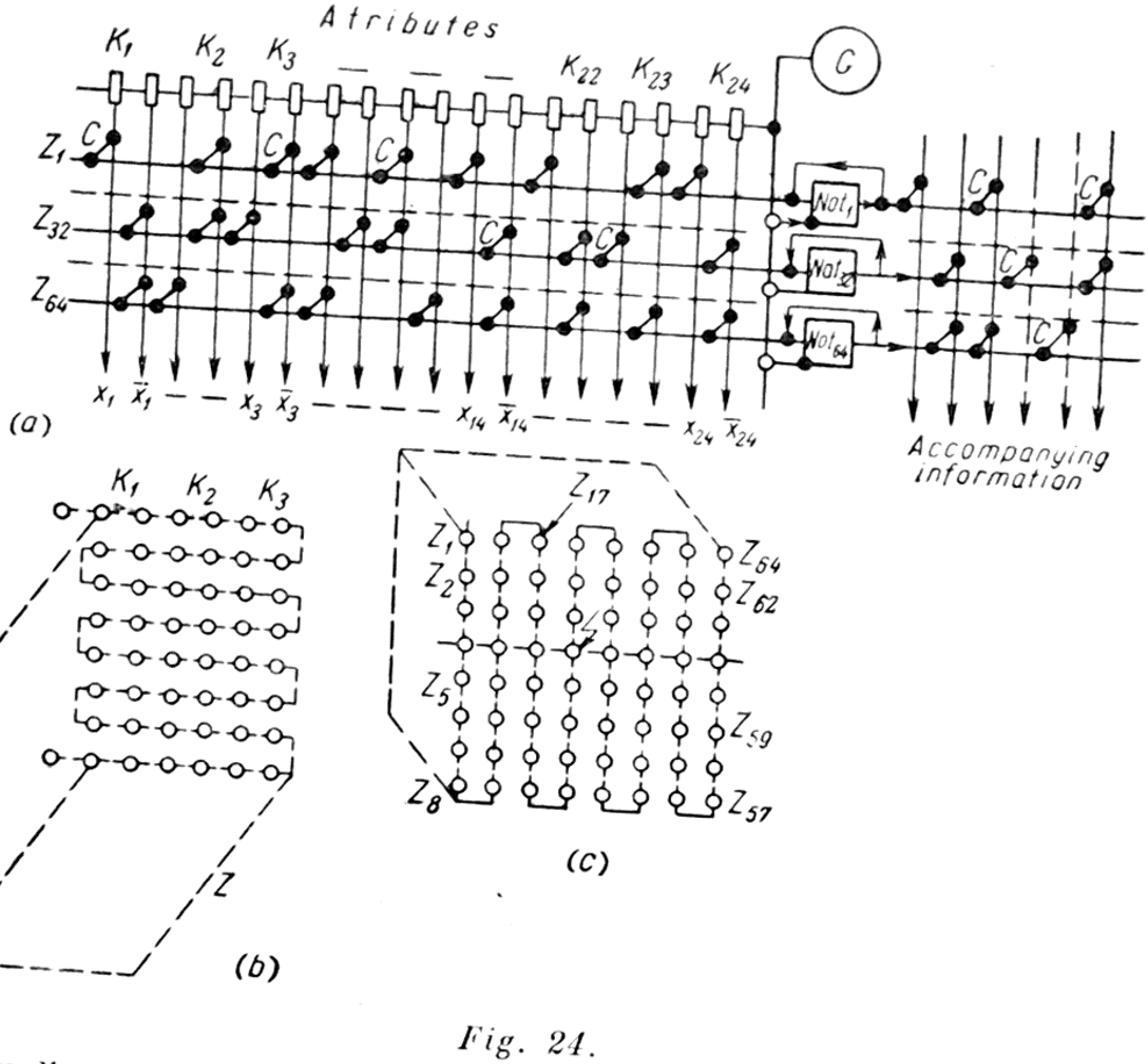



*Fig. 24.*

a—Key diagram of an associative memory ($K$—keys for setting attributes on bars $X$; $Z$—coupling bars; $C$—coupling elements between bars $Z$ and $X$; NOT—unlikeness keys; $G$—generator); $b$—keys $K$; $c$—bars $Z$

number $m$ in one unit is comparatively small (several thousand).

The associative memory permits the determination of the cell number which contains only the associative properties given by the address, and the reproduction of the rest of the information recorded in this cell.

Fig. 24 shows a diagram of the associative memory arranged on a plane.

The process of operation by the cycles is as follows:

1st cycle: keys $K$—bar $X$—bar $Z$—key *NOT*.

Result—a known cell number.

2nd cycle: power source—key *NOT*—bar $Z$—bar $X$.

Result—the content of the entire cell is known.

Coincidence signals from the elements *NOT* determine the addresses of the bars $Z$ coupled with them; then on the strength of these addresses the conventional *digital* address system with output bars comes into play.

The elements *NOT* can be coupled electrically to form a two-coordinate system in which one pulse, common for all, arriving from one excited element with coordinates $(X,Y)$, excites two bars $X$ and $Y$ of the digital two-coordinate system of the conventional memory in which the additional information about each associative property is recorded (in Fig. 24*c*, see arrow). In this case $2\sqrt{m}$ amplification links between the elements *NOT* and the bars of the second memory containing additional information is quite sufficient. It should be noted that not one but a whole group of keys $K$ should be set aside for each "notion".

Thus, for example, if a qualitative as well as a quantitative evaluation of the associative property is required, then the entire input field has to be divided into separate parts, in particular for writing down figures which can be expressed in any scale of notation (binary, ternary,.... $k$-nary).

As is evident after the input keys $K$ are set on the "attributes" only two cycles are required to obtain the additional information in the case where input signals and the recorded code coincide in one of the cells.

From the extended diagram in Fig. 24*a*, a two-coordinate system can be made up employing keys $K$ by folding it up "concertina-like" as shown in the diagram in Fig. 24*b*. As a result we have a rectangular-shaped design.

## Associative (Word) Address System

The operation of the digital address system described above may be illustrated by the example of a cloak-room. Each checked-in item has its own random number (each item of recorded information is supplied with a cell number). You can get your coat back without any trouble by presenting your tag. But if you lose the tag it is very difficult to find your coat in a big cloak-room filled to capacity. The search will proceed as follows: the cloak-room attendant will compare the description of your coat given by you with the specific features of other coats in the cloak-room. These features are: type of coat (overcoat, raincoat), colour, man's or woman's, etc. If several specific features are given then you will be told all the numbers under which there will be coats answering your description.

To find information in the machine memory by given attributes with the help of the digital address system is just as difficult as to find your coat in the cloak-room without the tag. It should also be noted that the number of cells in the machine containing information is over a million.

The associative address system serves for searching for information using specific properties or attributes. In this system given combinations of properties or attributes play the role of the addresses, and the reaction of the system are the numbers of those cells which contain the given combination of properties.

The system may respond to one number (with one and only one complete matching) and to several numbers (in partial matching), or respond in the negative (when conflicting properties are given).

The principles of organisation of the memory address system in logic machines, as was already mentioned above, should functionally correspond to the processes of information retrieval in the human memory.

Let there be $m$ fields ($m$ information sources). Each field has its own number or address in the list of fields.

Each such field may contain $n$ words (ideas). The maximum possible meaning of the full value $V$ of the recorded information will be equal to $m \times n = V$. The task, there-

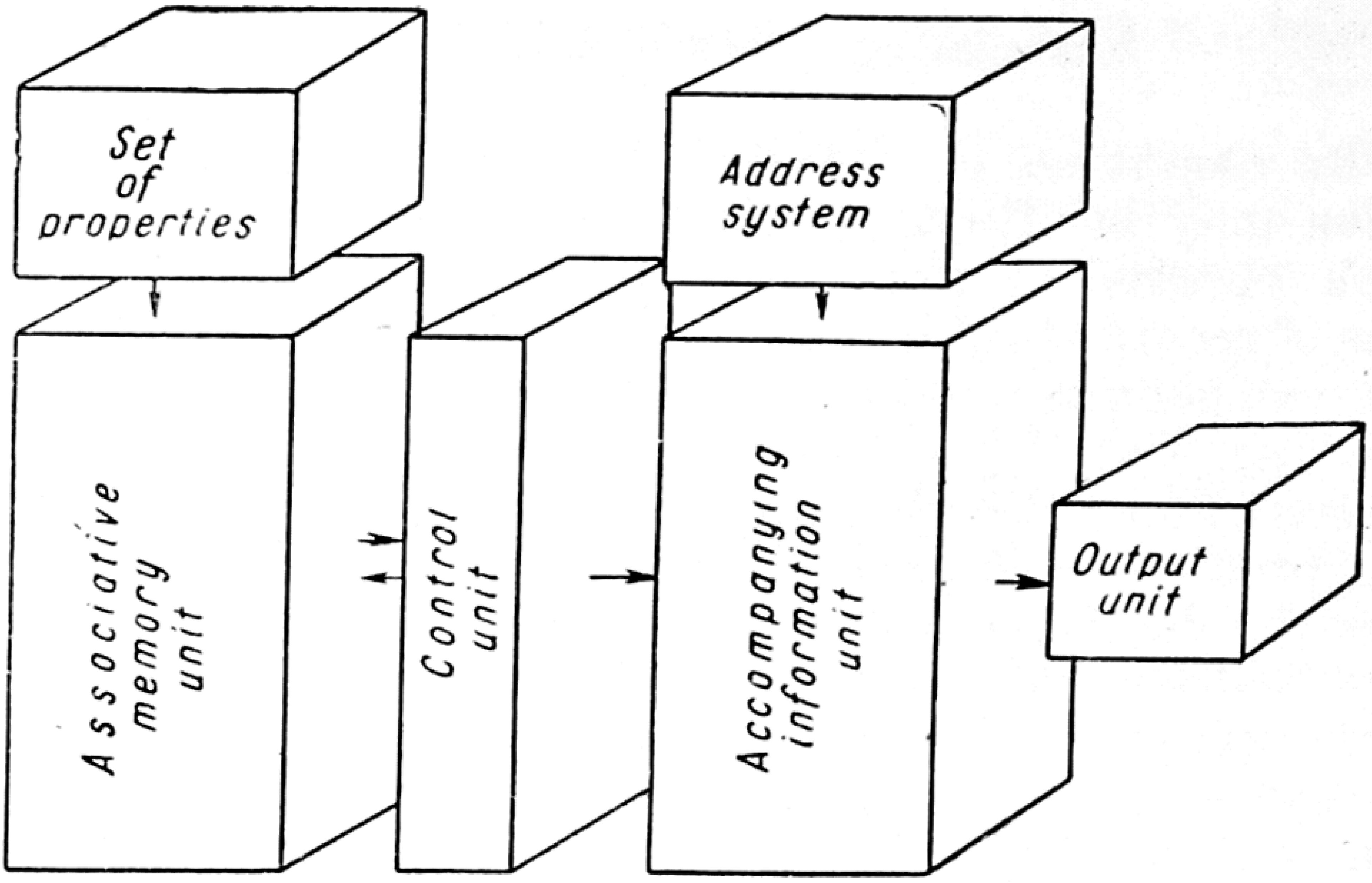



*Fig. 25.* Block diagram of an associative memory

fore, is to find by $n$ combinations of words the numbers (or addresses) of those $m$ fields (or objectives) which contain the given word pattern. In this case during the search the interrogating information will be the list of field numbers.

Assume for example that in such a machine memory is stored the information on the diseases affecting the human organism, and we want to find out the name of the disease and its treatment by combination of external and internal symptoms.

The block diagram of this machine is shown in Fig. 25.

The disease symptoms are recorded in the associative memory unit, for instance, on punched cards, the symptoms of one disease comprising one item of information. The number of information items will be equal to the number of diseases recorded in the associative memory.

Each symptom occupies its definite place in space (on the information field) and is recorded by a single code signal (zero or one).

Each unit of information of the associative memory represents a certain field of ideas or notions (the information field) where each idea (notion) may be expressed in

the word form by complete sentences. In the information field of the associative memory this idea (notion) is expressed by only one coupling element (the presence or absence) at the point of the field allotted to the given idea. The information about the methods of treatment, the name of the disease, etc., contained in the given unit of the associative memory is recorded in the conventional binary code in the *accompanying information unit.*

The control unit (Fig. 25) reproduces signals from the output bars *B* of all the information units of the associative memory. However, this information can arrive at the output unit only when the recorded information matches the interrogated combination. Then the address system of the additional information unit is switched on and information is read out from the selected field.

Here is an example of the use of the associative machine memory in the diagnostic machine which retrieves the names of the diseases by the given combinations of symptoms.

Suppose the following symptoms (properties) are given out of several thousand possible:

1) acute sudden onset of disease;
2) wet cough with discharge of sputum;
3) enlargement of the affected part of the thorax, with effacement of the intercostal spaces;
4) dyspnoea;
5) descent of the lower border of the lung;
6) diminished mobility of the lung's edge;
7) feeble or strenuous respiration;
8) intense sonorous rales;
9) increased transparency of the lung's field and intensification of the fasculo-bronchial pattern;
10) increased neutrophil count;
11) increased eosinophil count.

When all these symptoms are fed into the diagnostic machine the answer will be: bronchial asthma.

Another example of the use of the associative memory is the recording of the basic properties of the chemical elements. In this case by feeding into the machine a combination of properties determining physical, chemical and other properties of the element under study we will get the

name of the element in question and additional information about its other properties.

Assume that the following data is given pertaining to a certain chemical element:

| | |
|---|---|
| Density | 18.3 g/cm$^3$ |
| Atomic weight | 238.07 |
| Electrical conductivity | 2.6 |
| Melting point | 1133$^0$ |
| Boiling point | 3550$^0$ |

Uranium answers these properties alone.

Fig. 26 shows the diagram of an address system for the retrieval of information ordered by an arbitrary combination of letters. It is generally accepted that the letters of the words are written down with the help of a five-element telegraph code. A row of five keys of the AND type, excited when letters are typed, corresponds to each letter.

If we accept that the number of letters in a word does not exceed twenty then there will be exactly one hundred of those keys ($20 \times 5 = 100$).

Let the number of words in the Russian language be approximately one million (note that the vocabulary of Gor-

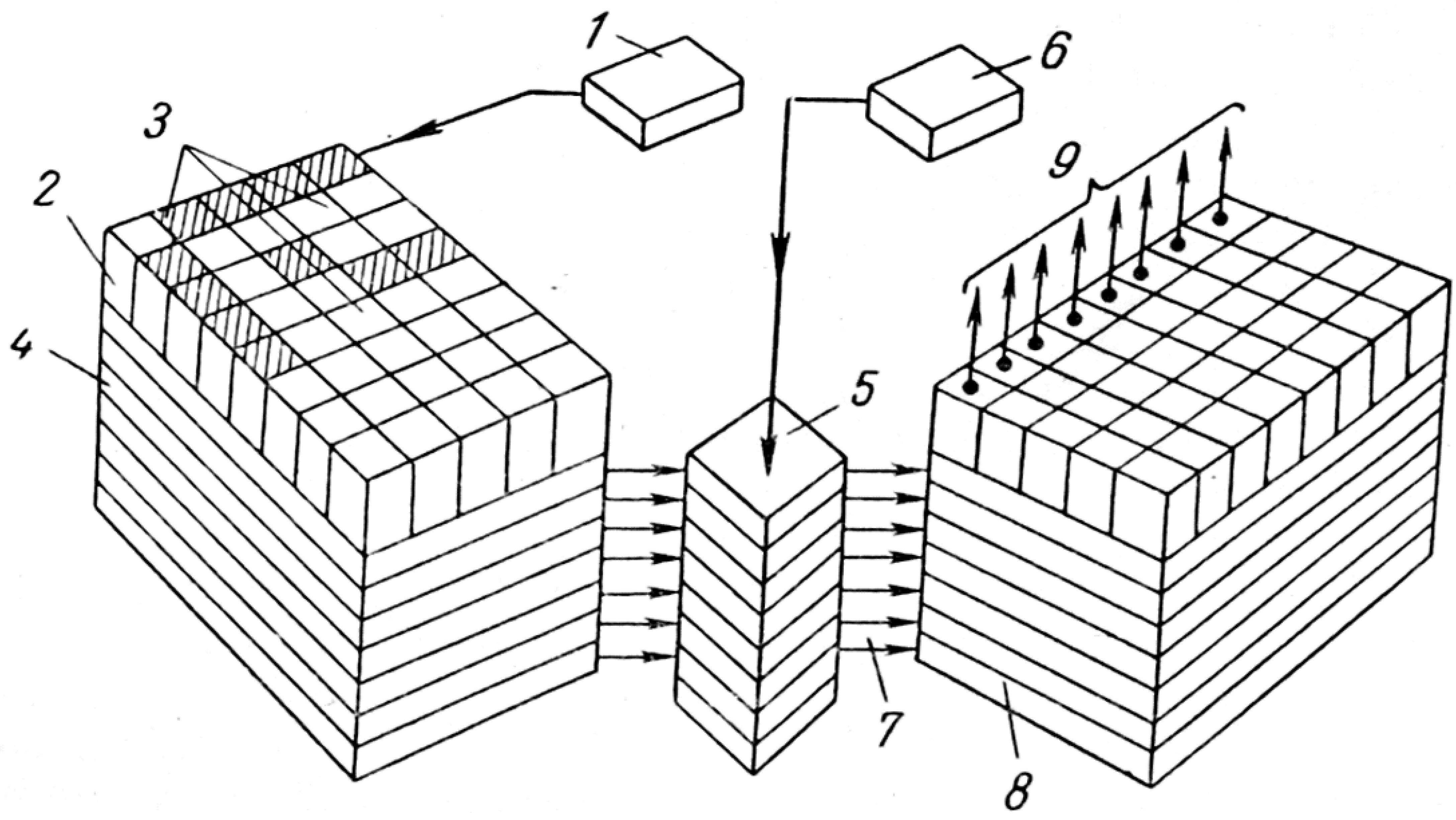



*Fig. 26.* Illustration of the principle of operation of associative memory

ky's works contains less than 20 thousand words). If we remember these million words it will take us only 20 bits to give an ordinal number to each word. These 20 bits in five-digit telegraph code may serve to write down only four letters.

A 10-letter word will require 50 bits in telegraph code. Therefore, 30 bits characterise the redundancy of information of the by-letter system, while 50 bits will be enough to denote any word selected from the stock of $10^{15}$ words and to number one hundred million million words (a hundred million times more than the accepted number).

The redundancy when recording words by letters, as we have already mentioned above, makes it more expedient to record information by the number of words in the dictionary. Economical recording requires an automatic dictionary which would produce the listed word number by the given letters.

The associative memory diagram shown in Fig. 25 can, in a particular case, serve as an automatic dictionary.

## Automatic Dictionary

This automatic memory (Fig. 26) comprises two units: the first one containing letter address system 2 with keys 3 and sheets 4. The second unit 8 has its own address system consisting of keys 5.

The keys serve as the links for transmitting the results of the operation from the first unit to the second.

Magnetic, capacitive or other elements are used in volatile or long-time memory devices as memory elements. In particular, ferrite cores or plates with one or several holes can be used for recording one bit. In this case, a high-speed secondary record can be made. Capacitive and other coupling elements can also be used for rewriting.

The structure of the *vocabulary* address system may be quite different. Since words in the given vocabulary represent certain definite letter chains, the interrogation process can be divided into a series of sequential operations. During the first cycle the machine seeks the address of the combination of the first two letters of a given word.

A two-coordinate address mesh comprising the keys AND is quite sufficient for this purpose. Let us illustrate this interrogation process with the example of translation from English into Russian. There are 26 letters in the English alphabet. Therefore, the first mesh for two letters should have 26 bars for the first letter and 26 bars for the second letter. The mesh will have $26 \times 26$ nodes. However, not all the letters can be combined in pairs at the very beginning of English words. For instance, the letters *m* and *b*, *m* and *c*, *n* and *d*, *n* and *f*, etc., cannot be so combined. On the whole there are 250 combinations of letters which should be recorded and reproduced in the memory unit as the addresses for the second address mesh.

The second mesh should have 26 bars for the address of the third letter of the given word and 250 bars for the address of the combination of the 1st and 2nd letters found with the help of the 1st mesh. In the given vocabulary there is a definite number of actual combinations of letters in threes. This number is by far below the product $26 \times 250$. Therefore, at the memory unit output controlled by the 2nd address mesh we should have the addresses of the combinations of the first 3 letters of the English alphabet.

The next third address two-coordinate mesh should have 26 bars for addressing the 4th letter of a word and a certain definite number assigned by the vocabulary for establishing the address of the combination of first three letters of the given word. The memory unit output should feed the addresses for the 4th mesh. And so on.

The number of meshes is $n$—1, where $n$ is the number of letters of the longest word.

When the address of the 5-letter word *truth* is looked for, the key AND operates in the 4th address mesh and excites the cell which reproduces the Russian translation of this word.

However, a longer word may be given, say, *truthful* which includes also the word *truth*. In this case the cell "truth" selected and excited by the 4th address mesh should contain not only the translation of the word *truth* but also give the address for longer words following in the 5th mesh.

Hence, it follows that some of the cells can contain the addresses of the additional information about the given word when it is part of a longer word.

The machine reads out the answer in sequence but very rapidly and the words are fed letter by letter sequentially, for example from the letter-by-letter automatic printer.

Many notions and associative properties can be graphically represented as a "tree" resembling the vocabulary address system. Hence the "tree" appears as the electrical model of these properties.

The associative and vocabulary address systems are very efficient in reading out information. Assume, for instance, that we wanted to summarise and record the working experience of a highly skilled operator who controls a very complex system of machines or some production process. Let the quality of production and the efficiency be determined by 50 qualitative factors (associative properties), the average numerical value of which may change from zero to 100 via 1. These factors are the positions, speed, acceleration, stress, pressure, the conditions of item, etc.

Record approximately 10,000 full cycles of operations ("words" or "sentences") in the machine memory. The processing of these records may show how the operator in question deals with the control tasks when certain combinations (associations) of deviations of various values from the optimal arise, and how his solution of these problems ("orders") affects the quality and productivity of the whole system. The best decisions ("orders") should be selected and recorded in the associative memory. Let there be approximately 1,000 of them. You can easily picture the way the machine memory will feed these decisions at the moment when a similar situation arises. Associative properties, that is, deviations of the values from those assigned, should serve as the addresses.

Various types of bit information can play the role of letters and words, therefore the device can be used not only as an automatic dictionary, but, for example, it can be used as the unit for address substitution of the memory cell numbers.

To this end the numbers of those memory cells which require address substitution are recorded in the first unit

(see Fig. 26), while new numbers should be recorded in the second unit. After setting the code of the numbers in the first address system, a new number can be obtained in the accompanying sheet.

This device can simultaneously play the role of an automatic dictionary, in which words stand for combinations of associative properties, and can be an associative memory which gives numbers of many meshes whose properties partially match those of the address. In this case a corresponding automatic device should be used to actuate those keys which will indicate that the associative properties of the request and those of the coded address match. A special signal can be introduced to determine whether there is one and only one answer (i.e., whether the machine operates as an automatic dictionary) or whether there are several answers.

The automatic dictionary can be used to minimise the volume of telegraphic traffic by several times. For this purpose a dictionary of words should be compiled which are commonly used in telegraph messages. Assume that such a dictionary has 1,000 words in its stock and that the average length of a word is eight letters. If we renumber the words then each word will require 10 bits for its transmission. Since the eight letters of an average word require 40 bits in a letter-by-letter transmission (and not 10 bits), the transmission of the words by figures cuts down the volume of telegraph traffic significantly.

We can also encode parts of the words, entire words or their combinations. Words are recorded in parts which very often have the same roots, stems, suffixes or endings. For instance, the word "automatic" is divided into two parts *auto* and *matic* and each part is coded.

For coding purposes special dictionaries of word stems, endings, suffixes, etc., are compiled.

Automatic dictionaries can be used for building up information in the given address and for replacing faulty addresses in the general system of the machine memory. When interrogating a memory unit with a damaged address (through a faulty part of the coordinate mesh or some other mechanical fault) the information belonging to this address may be lost. To avoid this the machine memory system

is provided with a certain number of spare addresses which draw information from the additional units. The information contained in the memory unit with the damaged address can be recorded in these units. Auxiliary addresses are recorded in the automatic dictionary so that the new auxiliary address corresponds to each damaged address, while all the damaged addresses are connected to the automatic dictionary in parallel with the common address system.

Information is built up much in the same way. Since the memory unit contains a definite volume of information for each address (a definite number of coupling elements and output amplifiers) it is impossible to add information in the usual way. This can be easily done with the help of an automatic dictionary. The address to which information has to be added is fed into the automatic dictionary. The new auxiliary address is found in the dictionary by this address (just as in the case of a damaged address) and after the information is supplied from the main unit to this address the automatic dictionary connects up the new address and the additional information contained in the auxiliary memory units is read out.

# Information Traffic in the Machine

## Sequential-parallel Shifting of Information

The long-time memory and the volatile memory reproduce information in parallel. In a single time cycle the machine memory reproduces $m$ signals, where $m$ can be 1,000 bits. These $m$ signals are fed by command to the computer unit.

In some cases information from the given memory cell has to be reproduced in time sequence. For instance, when information is produced through loudspeakers it should be reproduced in time sequence. The same is required when information is fed into a telegraph line. The sequence is of special importance when an information machine is connected with a great number of subscribers. They can be either information machines or logical devices with which our machine exchanges information.

For this purpose a memory of sequential-parallel action was developed which when ordered shifts information:

1) in parallel (by pulse packets from one arbitrary cell to the other) and

2) in series—inside the memory cells, just as in the discriminator.

In the first case the memory operates as a volatile memory of parallel action (MVM), while in the second case it operates as a system of discriminators or as a multitrack magnetic drum. In the second case information is received and reproduced from the memory cells by step (or cycle by cycle), one signal per cycle.

This system of information shifting is illustrated by the example of six players passing balls in four lines (Figs 27-29). Each line of players corresponds to one memory cell with six memory elements. On the order "shift sequen-

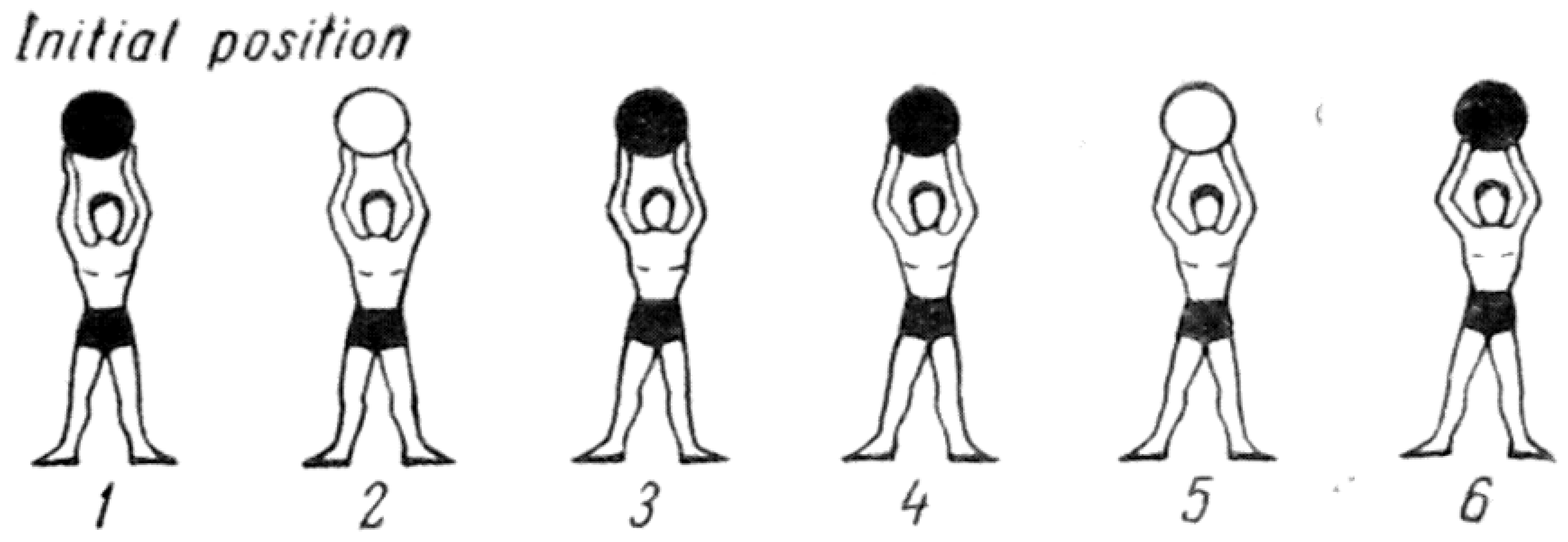



*Fig. 27.* Initial position of information

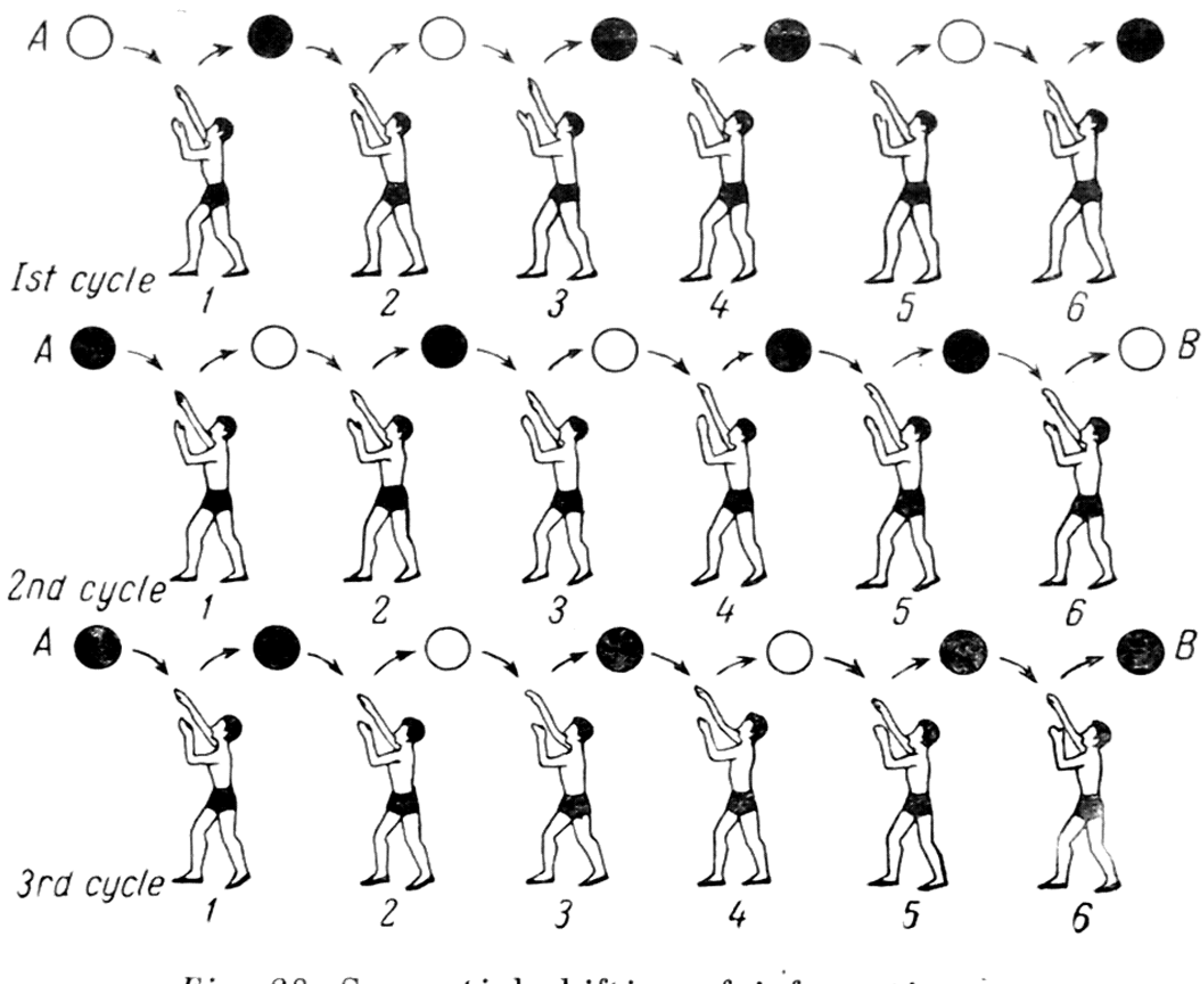



*Fig. 28.* Sequential shifting of information

tially", black and white balls are passed from hand to hand along the line.

The first player in line (Fig. 27) gets the ball from an outside player and the last one in line gives the ball away. The ball is passed on a signal corresponding to a unit cycle. This case illustrates the operation of four discriminators shifting information synchronously under the action of one

common source of cycle signals. Here is how the balls are passed in the third line during the three first cycles.

The initial arrangement of the balls (Fig. 28) can be coded as 101101 (the black ball is "1" and the white is "0"). During the first cycle information is shifted by one step and one more ball, for instance white, can be received from line *A*, while the last man in the line passes the black ball to the line *B*. Then the arrangement of the balls will be 010110.

In the second cycle information is shifted by another step and one more ball is received, for example black, while the white ball is passed to line *B*. The arrangement of the balls will correspond to code 101011.

In the third cycle the procedure is the same. One more ball, for instance black, is received from line *A*, and the last man in the line feeds the white ball to line *B*. Now the arrangement of the balls will correspond to code 110101, etc.

If the last player in the line passes the balls to the first man in the same line, then the balls will be passed along a closed circle formed by the players. The relative position of the balls in this case will always be the same, but the balls shift with each time cycle (it is as if the arrangement of the balls is memorised). The line cannot accept and pass the balls to the outside. This case illustrates the operation of the cycle discriminator with feedback, for the temporary storage of information.

Assume that in the third cycle the last man in the line passed the ball to the first player in the same line. The arrangement of the balls was 110101. After the fourth cycle the arrangement will be 111010, after the fifth—011101, after the sixth—101110, etc., up to the ninth cycle after which the arrangement of the balls will be just as it was after the third cycle. If we consider the arrangement of the balls after the third cycle as the recorded initial information, then in order to obtain it in the same initial form the balls should be passed just as many times as there are players in a line. The number of ball passes can be called a cycle or a period of circulation of the information in the discriminator.

Now assume that on some other order the balls can be passed from one line to another line, but each player of

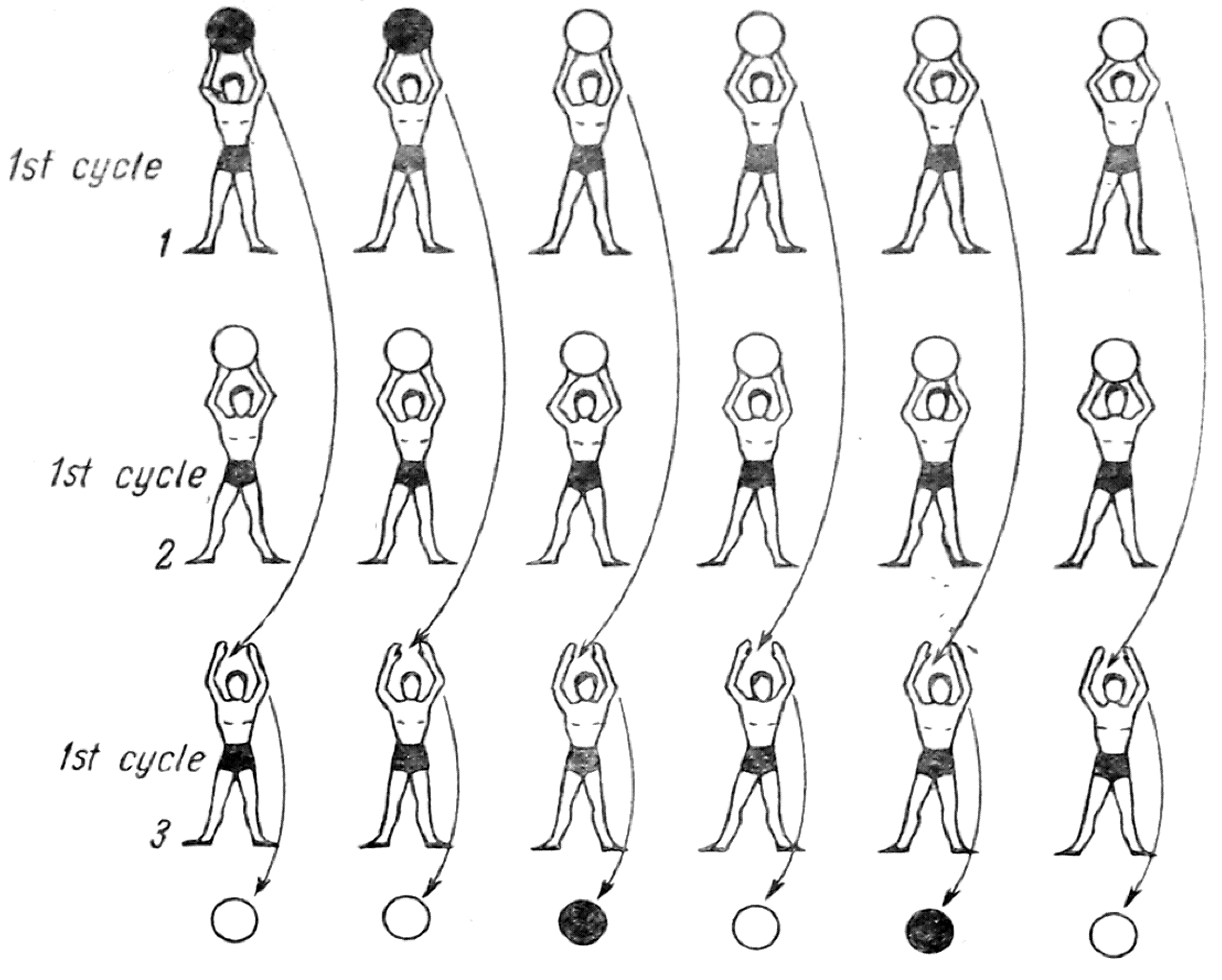



*Fig. 29.* Parallel shifting of information

one line can only pass the ball to the player in the other line who has the same ordinal number (Fig. 29). Those in the receiving line should beforehand pass on their balls and be ready to receive the new ones.

This case serves to illustrate the passage of information in parallel in packets from one memory cell to the other.

Fig. 30 shows the diagram of the packet-by-step system of memory (discriminators). The system is based on volatile memory.

Each bar with memory elements in coordinate $X_i$ or $Y_i$ can be regarded as a separate discriminator. The number of memory elements in any of the bars in coordinate $X$ is $m$, and in coordinate $Y$ is $n$ ($m$ and $n$ are the numbers of coded categories (binits) in the information along coordinates $X$ and $Y$).

Memory elements are ferrite cords of the type employed in the magnetic volatile memory but with four bars passing through them along coordinates $X$ and $Y$. The read- and write-bars of each coordinate $X$ and $Y$ are divided.

Information can be recorded or read out with the help of a control unit in any combination in series or in parallel on coordinate $X$ and $Y$. It comprises two decoders $D_x$ and $D_y$ and the source of the address control signals. (For simplicity Fig. 30 shows only decoder output windings designated $\overline{X}$ and $\overline{Y}$.)

Here is a simple system comprising 48 cores (Fig. 30).

**Sequential group recording and reading out information on coordinate Y.** All the binits of information retrieved from the machine memory arrive in parallel at the input windings $X_1$, $X_2$,... $X_6$.

The code signals create pulse currents exciting (in accordance with the arriving code) ampere-turns in the cores equal to $aw_x$, but which are insufficient for the reversal of the core magnetic polarity in these bars.

The addresses of the bars $Y$, beginning with $Y_1$ and terminating with $Y_4$ arrive in series at the decoder $D_y$, from the control unit. Pulses appear at the bars $Y_1$.... $Y_4$ creating ampere-turns $aw_y$ in the cores (see Fig. 30) which together with $aw_x$ are quite sufficient for changing their polarity.

Thus during each operational cycle of the pulse source, information is recorded in a packet in the bar (discriminator) on coordinate $Y$ in which a pulse from $D_y$ is acting. Consequently, in four cycles all the six discriminators will store up information of the total volume of $6 \times 4 = 24$ signals.

For the reading out of information in packets the control signals arrive in each cycle from the discriminator $D$ to bars $Y$ (in the same sequence as during recording). To reverse the polarity of the cores and to obtain output signals at the amplifier inputs $V_{x_1}$.....$V_{x_6}$ it is sufficient to have $aw_y$ ampere turns. At each given moment information is read out from one bar $Y$ (of the discriminator).

Packet recording and reading out can take place during each cycle but with a time shift. For instance, in the first cycle code signals arrive at bars $X_1$....$X_6$ while a recording

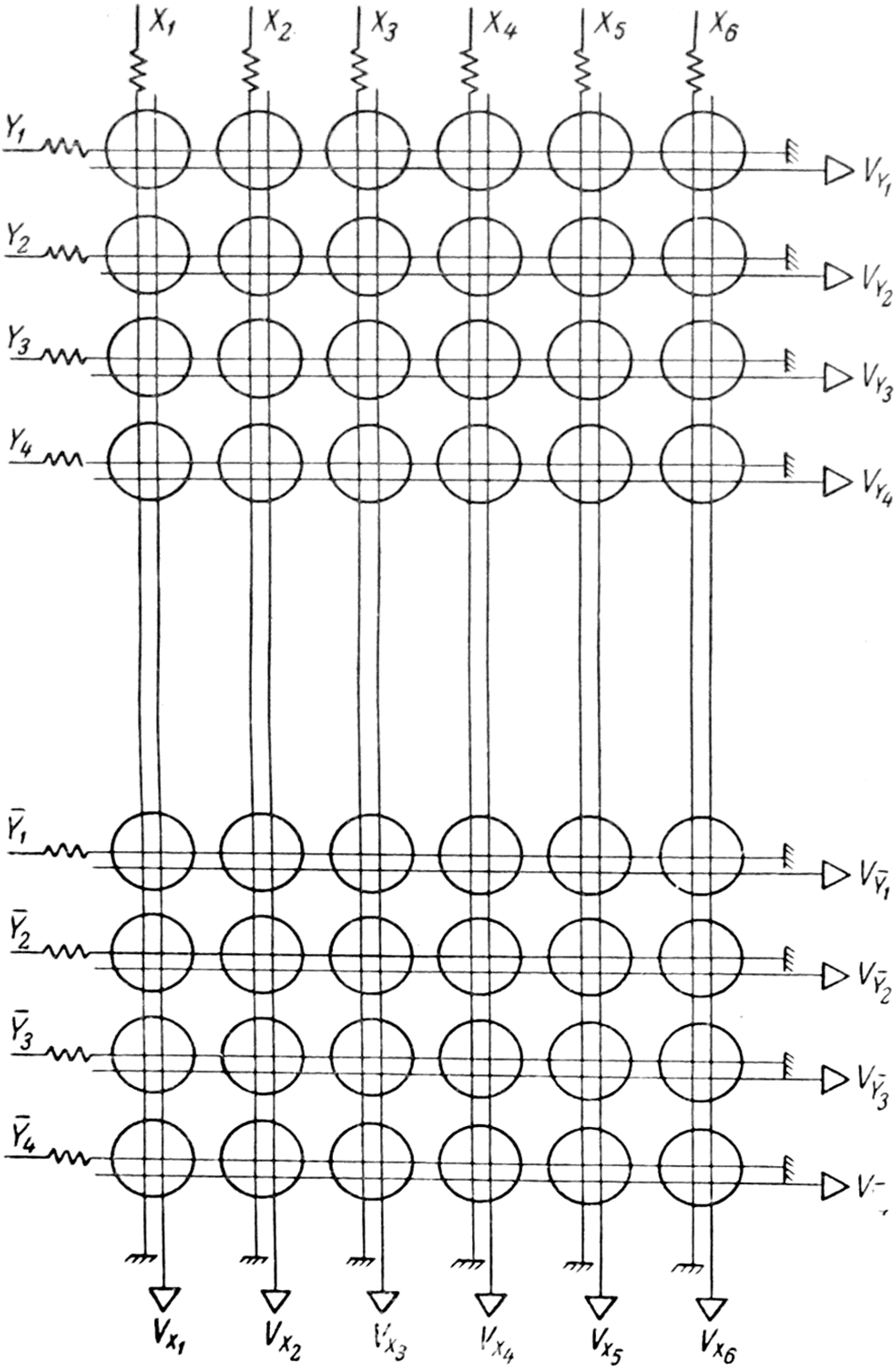



*Fig. 30.* Key diagram of the packet-by-step discriminator $V_x$, $\overline{V}_y$—amplifiers; $X$, $Y$, $\overline{Y}$—read-out and read-in bars

control signal arrives at bar $Y_2$. Then information is recorded in discriminator $Y_2$. The read-out signal is fed to bar $\overline{Y}_2$ in the interval between the first and the second cycle, thus allowing information previously recorded in this bar to be read out. During the second cycle another recording takes place, for instance in bar $Y_3$, and information is read out from bar $\overline{Y}_3$ in the interval between the second and the third cycle.

**Sequential representation and parallel read out.** The memory of this type permits the making of a sequential representation and a parallel read-out of information on any co-ordinate $X$ or $Y$. This means that in one cycle, for example, code signals can be fed to bars $X_1 \ldots X_6$ and the recording control signal to bar $Y_2$. Information will be recorded in the bar $Y_2$. A read-out signal can be fed, for instance, to bar $X_2$ in the interval before the next cycle. Then information will arrive at amplifiers $V_{y1} \ldots V_{y4}$ only from the cores situated on this bar.

The memory for parallel and sequential representation can be regarded as a matrix having $m$ columns and $n$ lines, a matrix which can be used for the selection of any line and any column in any combination in the process of recording or reading out information. A matrix can be engaged by a unit of information recorded in all the lines and columns of the memory. In this case, the same unit of information may consequently be read out from one line or column to the other, as if it were shifting from one discriminator to the next. These discriminators afford an efficient and very convenient system of information shifting.

## Telelibrary

We have already said that the rapid growth of the quantity of published matter, the accumulation of a tremendous amount of patents, and other such information in archives make it more and more difficult to put all this material to use, since it takes much time to search for and retrieve it.

The problem of looking over the stored material is solved most efficiently in the library itself with the help of information-carrying microfilm and a projector. The stills

selected by the address indices can be quickly projected on the screen and transmitted over the TV channels. At this stage a new problem arises of creating libraries and archives of a progressive type which will permit the examining of material stored in them via communication lines (telephone or telegraph) from any locality. We shall call such progressive undertakings *telelibraries* and *telearchives*.

Besides large-capacity long-time memory these telelibraries will require the address control system and a unit for transmitting information to subscribers.

A large-capacity long-time memory reproduces in parallel the recorded information at a speed of scores of millions of bits per second. The subscribers can receive information sequentially signal by signal at the speed of visual examination of information (one word per second), or at the speed of perception by ear, or at the speed of reproducing the text on a typewriter (several thousand bits per minute).

Those are the technical difficulties generally arising when one system of machine memory of *parallel* action supplies $m$ subscribers' lines with information sent out *sequentially* in time.

Fig. 31 shows the telelibrary block diagram. Each subscriber dials the code number of the required information in the unit *6*; then this information arrives at the receiving device *7* and is retained there as long as the subscriber needs it.

If a TV cathode-ray tube is used for this purpose, then the ordered text appears on its screen. The text can be ordered (in unit *6*) to change the pages by pressing a button ("leafing").

The subscriber uses his control unit to call first of all the telelibrary subject or card catalogue to find the code of the addresses of the required information, and then to order page by page transmission of this information.

In contradistinction to conventional libraries, in the telelibrary one and the same information source can be used simultaneously by many subscribers, although there is only one copy of it recorded in the machine memory. The telelibrary subscriber lines can be connected up to the automatic telephone exchange. Each subscriber should be provided with special equipment which consists of the two parts—

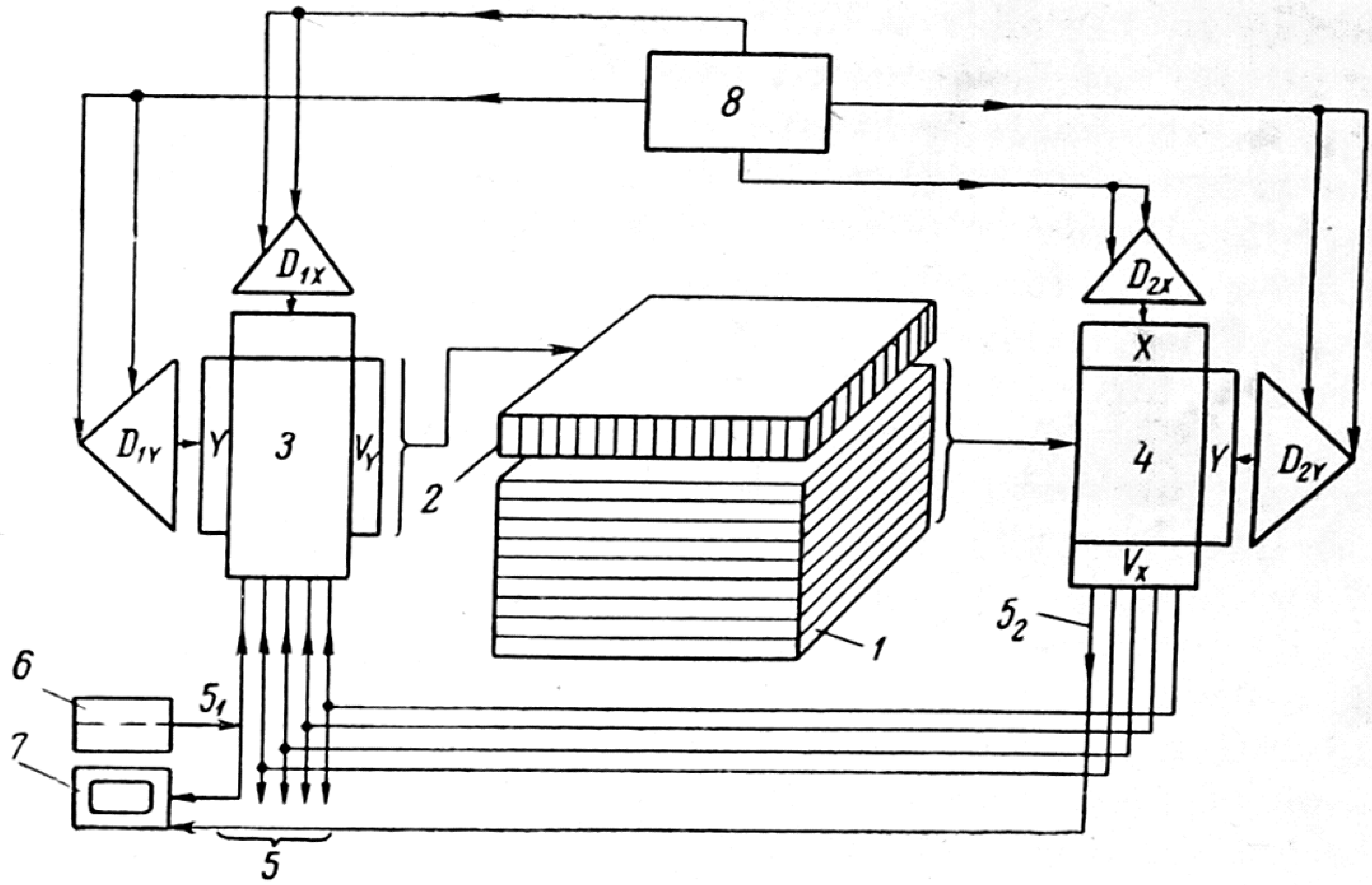



*Fig. 31.* Block diagram of a telelibrary

*1*—machine memory—"library"; *2*—address system; *3* and *4*—packet-by-step discriminators; *5*—coupling channels; *6*—subscriber's transmitting apparatus; *7*—subscriber's receiving apparatus; *8*—control unit; $D_x$, $D_y$—decoders; $V_x$, $V_y$—output amplifiers

receiving *7* and transmitting *6*. The transmitting part may have a keyboard for dialling the code (the address of the required information), or a special dial. The receiver can be either a TV screen with an afterglow for visual reading of the information on the magnetic tape, or a typewriter, or finally an apparatus for receiving information by ear. The subscriber can receive information simultaneously on all types of receiving apparatus or on one of them.

The telelibrary (or telearchive) has the long-time machine memory *1* containing information material recorded in it in bit form, address system *2*, two packet-by-step memory units (discriminators) *3* and *4*, and the control unit *8*.

Each subscriber is connected with the telelibrary by two lines (channels). The first channel links up the transmitting part of the subscriber's apparatus with the input discriminator *3* for transmitting the code of the required information from the subscriber to the telelibrary. The second channel links the subscriber's receiver with the output discrimina-

tor *4* and transmits the information coded signals from the telelibrary.

Since communication between the subscriber and the telelibrary is remote via telephone and telegraph lines, the traffic of information between the subscriber and the telelibrary is sequential so as not to increase the cost of communication systems. Inside the telelibrary information is shifted in parallel.

The address code signals are fed into the first channel $5_1$ by pressing a key in the subscriber's transmitter or by dialling a number. These signals arrive at the input discriminator *3*, the principle of operation of which was described above (see Fig. 30).

The number of bars on coordinate $X$ of the discriminator *3* is equal to the number of subscribers $m$ linked up with the telelibrary, while the number of bars on coordinate $Y$ equals the maximum number of bits in the information address code $n$. For example, if there are 1,000 subscribers and the volume of information in the telelibrary contains one million addresses, then the number of bars on coordinate $X$ is 1,000, and the number of bars on coordinate $Y$ is 20 (any address out of one million addresses can be determined with the help of 20 binits).

The code number pulses from subscriber $K$ arrive at bar $X_K$ of the discriminator (see Fig. 30). All $m$ subscribers can dial the addresses simultaneously with the pulses from each of them arriving at its own discriminator $X_i$; these pulses are recorded sequentially in time and travel in bars $X_i \dots m$ along the coordinate $X$. For this purpose cycle recording signals are fed from the common control unit *8* to bars $Y_1 \dots n$.

The cycle recording signals are fed to bars $Y$ as long as the telelibrary operates, since the recording signal from the control unit after $Y_n$ goes again to bar $Y_1$, etc. No matter when the subscriber dials the address, it can be written in in the discriminator *3*. In the interval between the cycle recording signals information is read out in parallel from bars $X_i$ in which it has been stored (address code).

The addresses are reproduced from the discriminator bars when the dialling of the given address is completed. To this end several pulses arriving at bar $X_i$ of the discriminator are read automatically at the end of dialling.

The read-out control signal arrives sequentially at all bars $X_{1 \dots m}$ from the control unit, but information can be read out if the end of the dialling signal is recorded in the bar. The addresses are read out and reproduced all the while the telelibrary operates, because after bar $X_m$ the signal is fed once more to bar $X_1$, etc.

The address read out from bar $X_k$ arrives in parallel via amplifiers to the machine memory address system, and the required information is retrieved by this address. The output discriminator *4* receives information from the memory and transmits it to subscribers. Accordingly, the number of bars on coordinate $Y$ equals the maximum number of coded categories in the received volume of information $n$, while the number of bars on coordinate $X$ equals the number of subscribers $m$. For instance, if the number of bits of the information coded signals at any address does not exceed 2,000 and the number of subscribers is 1,000, there will be 2,000 bars on coordinate $Y$ and, as in the previous case, 1,000 bars on coordinate $X$.

Information retrieved from the memory is recorded in the bar $K$ of the packet-by-step discriminator *4*. When the address dialled by the subscriber $K$ in bar $X_k$ of the discriminator *3* is read out, bar $X_k$ of the discriminator *4* is simultaneously being prepared for the reception of fresh information, while the information retrieved from the memory by the subscriber's address is sent to him.

Read-out signals arrive continuously at bars $Y_{1 \dots n}$ from the common control unit and the discriminator *4* shifts information in series along coordinate $X$.

Just as all the $m$ subscribers can simultaneously dial information addresses in discriminator *3*, the distribution of information at the discriminator *4* output also takes place in parallel to all the subscribers, although sequentially in time. The information to subscriber $K$ will be fed from bar $X_k$ of discriminator *4*, while to all other subscribers the information will be sent from the corresponding number of the bar $X$ of discriminator *4*. If the subscriber did not request information, no signals are sent to him, since there will be no end-of-dial signal in the discriminator in the bar $X$ corresponding to this subscriber.

Information arriving in series from discriminator *4* in

binary code is memorised by the subscriber's receiving unit *7* and is stored there until the subscriber presses the button "leafing" and rubs out the information from the receiver discriminator. From the receiver unit the information via the converter arrives at the receiver proper.

Conversion is required when information is received visually or by ear, and is not needed when it is typewritten or recorded on tape. It is assumed that it will be written down in telegraph binary code and decoded by the typewriter itself. If a newly developed tube, the charactron, is used for visual information, reading or printing, then in this case too, it does not have to be converted. The tube contains a screen-mask with letters and other signs of the alphabet. When the information signals arrive, the tube itself selects a letter or a sign by the code which has arrived. Letters of the arriving text appear on the tube screen.

When a cathode-ray tube is used with persistent afterglow ensuring the reliable reading of the text, the circulation discriminator and the conversion unit become unnecessary in the receiving apparatus. The text is read directly from the signals arriving from the output amplifiers of discriminator *4*.

As can be seen from the description of the principle of operation of the telelibrary, the information is transmitted in parts—quantums. The telelibrary capacity is determined by the speed with which information is retrieved from the main memory *1* and by the volume of separate parts of information (for instance, by the number of bits in it). Thus if a subscriber can read part of the received information, say in time $\tau$ and the speed of its reproduction is $v$ then the telelibrary can serve $\tau \times v$ subscribers.

If the information feeding speed is $v=10^4$/sec and the subscriber can use each part on the average in 10 sec, then the telelibrary can serve $10 \times 10^4 = 10^5$ subscribers. It means that while one subscriber reads in 10 sec the information fed to him in $10^{-4}$ seconds, the commutating unit will have time to feed the same bits of information to another hundred thousand (less one) subscribers.

Time $\tau$ is determined by the efficiency of the subscriber's receiving apparatus. If this is a cathode-ray tube then $\tau$ is equal to the afterglow duration.

The rate of operation of a telelibrary is determined by the frequency of the cycle pulse source in the control system *8*.

Matching the subscriber's apparatus with that of the telelibrary also presents a problem since the address signals sent by subscribers should be in perfect synchronisation with the cycle pulse source of the telelibrary control system.

Synchronisation can be ensured by sending additional synchronising pulses to the subscriber apparatus.

All the difficulties connected with the problem of designing a telelibrary can be solved by using the types of machine memory, automatic dictionaries, address systems and discriminators already developed.

For this idea to be realised in practice the mass production of new types of equipment (i.e., machine memory, commutating devices, etc.) should be initiated.

## Information Machines and Telephone-telegraph Stations

The problem of machine information is closely connected with the construction of a great number of information machines, specialising in various branches of science and technology and situated in various towns. Each information machine should be connected with subscribers who will supply the machine with information and also connected with those who will use the information processed by it.

The problem of information exchange between machines and subscribers is a problem of prime importance; it is closely connected with the automation of telegraph communication. Automatic telegraph stations (subscriber telegraph—ST) should in the future find far greater application than they do today. It is convenient to combine automatic telephone offices and the subscriber telegraph into automatic telephone-telegraph stations (ATTS).

Since information machines receive, process and transmit information expressed in letters their development and application should promote the creation of an extensive network of ATTS.

Packet-by-step discriminators for shifting information may promote the development of automatic telephone-telegraph stations since they are very convenient for pulse commutation. Actually the operations of the telelibrary and of the automatic telephone-telegraph station are similar, the only difference being that the ATTS has no machine memory; a subscriber makes a call and communication is established directly between two subscribers.

Fig. 32 shows a diagram comprising two sets of memory, the cells of which are linked up with the subscribers' circuits (subscribers or ATTS cord pairs). The system requires additional converters of telephone currents into binary code (into digital information) for speech transmission. Instantaneous values of telephone currents should be converted into bits approximately 8,000 times per second. The use of seven bits is quite sufficient for recording each instantaneous current value ($2^7=128$).

The design principle of the commutation system can be illustrated as follows:

Assume that each subscriber has two tape recorders. One to record his own speech, and the other one to reproduce the speech of the second subscriber with which the first one has established communication by dialling his number through the automatic telephone office. Consequently, one tape recorder should reproduce the speech of the first subscriber while the other one should record his own speech.

Assume next that some magic device transfers magnetic tapes from one subscriber to the second one in a millionth of a second, so that the subscribers do not even experience breaks in conversation. There is only one such device for every 1,000 subscribers. If the number of subscribers is 1,000 the total time of transferring magnetic tape will be $T=2m\tau=$ $=2{,}000\tau$, where $\tau$ is the time of one transfer (commutation). In this case the duration of a single recording in the tape recorder is determined by the total commutation time $T$. If $\tau$ equals 5 microseconds (200,000 transfers per second) then the recording time in the given case will be 10 milliseconds. Clearly it is impossible to transfer 2,000 tapes in 10 milliseconds by mechanical means. For this purpose a recording and commutating electronic system should be used; the

magnetic volatile memory of sequential-parallel action (packet-by-step discriminators) in particular.

We shall remind you that sound is recorded and reproduced with the help of these tape recorders *in series* in time while the magnetic tapes are transferred from one subscriber to the other *in parallel*.

Let us calculate the number of memory elements required in each discriminator in our case. A memory of 560 elements in the magnetic memory discriminators is required for 10 milliseconds for 8,000 instantaneous values of seven bits per second.

With the help of this calculation we can now determine the number of memory elements required. It turns out that the memory volume is characterised by the following data: number of addresses—1,000; number of memory cores—1.12 million; operational speed—200,000 recordings per minute (5 microseconds per recording). Thus the memory can be realised in practice.

It is of importance that all the commutation in the discriminators takes place at the central station, while each subscriber is connected with the station by one wire pair.

Specially developed signal delay lines can also be used as such discriminators. They should have the following properties: passband—up to 8,000 c/s; delay time—about 5 milliseconds; read-out winding that should be capable of parallel reproduction of instantaneous values upon the arrival of special read-out pulses; minimum attenuation in the delay line. There are no such lines at present but if use is made of elements capable of working at very low temperatures such lines may be developed in the future.

The use of signal delay lines makes it possible to eliminate the devices required for the conversion of the conversation currents into digital code.

At present we can speak of the use in the automatic telephone stations of sequential-parallel memory employing digital code only.

Thus in the system under discussion information arriving from each subscriber is received by memory units (discriminators), gated and transmitted periodically (in a fraction of a period) in parallel to other discriminators, from which it is fed in series to subscribers.

The duration period being $T$ and the number of subscribers $m$, the commutating unit should transmit all the information which has been stored in discriminators during period $T$, i.e., the entire conversation between the subscribers in time $T$. We shall call that part of the information which has been stored during period $T$ a *pulse packet*. Therefore, the process of operation of the station will be as follows: first the storing of information in the $m$ discriminators and consequently commutating (transferring) the pulse packets from one subscriber to the other.

The transmission of audio oscillations is based on the conversion of these oscillations into binary code. The well-known converters of continuous voltage values into digital code and back again, i.e., converters, which are known as *digital modulation* units, can be used for the purpose.

The picture is the same when an automatic telephone station is used to transmit and commutate telegraph signals in five-digit bits, or any other information in binary code between the subscribers.

Multiplexing of the long-distance communication lines will invariably lead to the development of devices converting speech into a series of frequencies which will be transmitted by the numbers of these frequencies and by the amplitude digital values (a synthetic telephone). Calculations show that one conversation will require only about 300-500 pulses per second. In this case pulses in bit form recorded as the series of units and zeroes, for example, in the form 1001110101 ... 0011001 ... arrive at the automatic telephone station from the subscribers.

The subscribers' addresses should also be expressed in the bit form. For this purpose dials can be made so that they feed the decimal figures from zero to nine in bit form using four binary signs (0000, 0001, 0010, ... 1001) which if necessary can be easily converted into binary numbers.

Fig. 32 shows a block diagram of one such automatic telephone-telegraph station.

All the subscriber lines $A$ at the station terminate in converters $C$ which convert speech into binary code. The converters are connected with receiving discriminators $D_r$, output discriminators $D_{out}$, and marker $M$.

The subscriber number pulses arrive at marker $M$, where

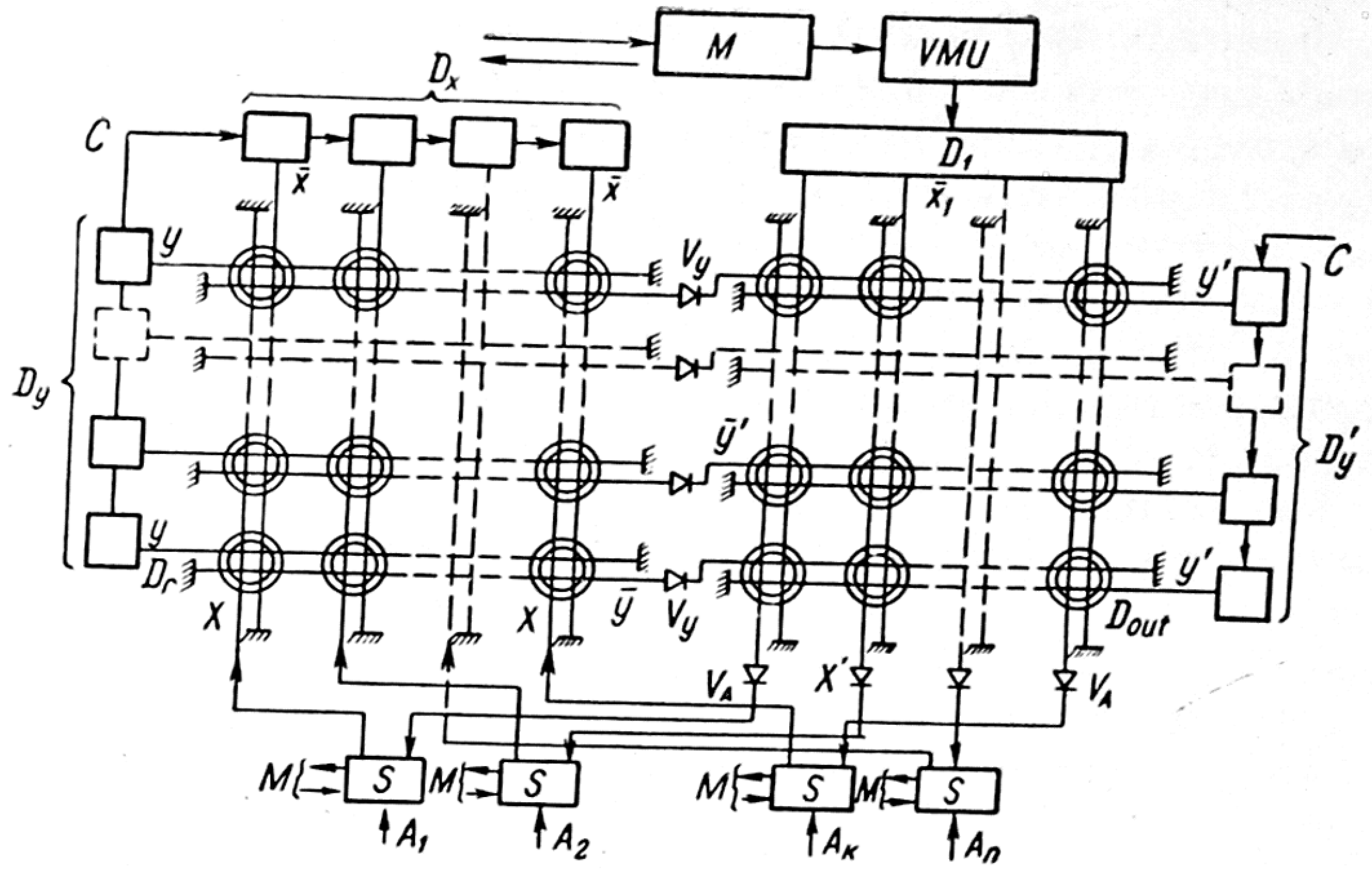



*Fig. 32.* Block diagram of an automatic telephone-telegraph station ATTS

$A$—subscriber lines; $M$—markers; $S$—converters; $D_r$—receiving discriminator; $D_{out}$—output discriminator; $D_x$ and $D_y$—distributors; $VMU$—volatile memory unit; $V_y$, $V_A$—amplifiers

the numbers of the line called and of the caller are recorded in the special discriminators. Then these numbers are sent to the volatile memory unit VMU controlling the commutation of the speech circuit between the subscribers via decoder $D_1$. Speech is commutated, transmitted and received with the help of a sequential-parallel memory (packet-by-pulse discriminators).

Distributors and decoders control the work of the memory. The entire system is synchronised with the help of counter $C$ with the pulse oscillator. Here now is the process of operation of the discriminator $D_r$ when recording sequential signals arriving from the subscribers.

Two bars and two rows of elements correspond to each subscriber (or cord pair)—one bar and one row of elements at the receiving discriminators (on the left in Fig. 32) and one bar and one row of elements at the information read-out discriminators (on the right in Fig. 32).

Distributor $D_y$ is controlled by counter $C$ feeding into its input one pulse in $n$ cycles of the operation of a common oscillator (Fig. 32), where $n$ is the number of horizontal bars in the discriminator $D_r$. The distributor $D_y$ feeds preparation pulses $i_p$ to the bars of discriminator $D_r$ in series in time with the operation of the oscillator. The recording pulses $i_{write}$, positive for recording "1" and negative for recording "0", are fed to vertical bars $X$ of the discriminator $D_r$ in accordance with the information arriving from the converters $S$ in synchronisation with the oscillator.

The recording current records the information arriving from $m$ conversing subscribers in the cores of one horizontal row of discriminator $D_r$.

After $n$ cycles information is recorded in the cores of all the horizontal rows of discriminator $D_r$. Following one operational cycle of the distributor ($n$ cycles) another cycle begins and so on. In $n$ cycles all the elements of the discriminator accumulate $m \times n$ bits of information. In the same $n$ cycles information should be recorded in the discriminator $D_{out}$ elements packet-by-packet. For this purpose the second distributor $D_x$ receiving single pulses from the same counter $C$ operates, following each cycle of the distributor $D_y$ with a certain phase lag. The distributor feeds read-out pulses in series to the vertical bars $\overline{X}$. The cores with zeroes do not change their state and, therefore, do not send pulses to the read-out bars.

Bars $\overline{Y'}$ for reading out parallel information are connected with amplifiers $V_y$ feeding the recording current $i_{write}$ to the horizontal bars $\overline{Y'}$ of the discriminator $D_{out}$. The preparation current $i'_p$ is also fed into the discriminator $D_{out}$ cores onto the vertical bar $\overline{X'}$ selected by decoder $D_1$. Information determined by the polarity of the recording current $i'_{write}$ is recorded on the cores of this bar.

All the $n$ bits from one of the storage rows of the discriminator $D_r$ are transmitted in one cycle to the corresponding elements of one storage row of the discriminator $D_{out}$. The distributor $D'_y$ controlled by counter $C$ and situated in discriminator $D_{out}$ sends read-out pulses $i'_{read}$ to horizontal bars $y'$ synchronously with distributor $D_x$ and with a certain time lag. Subscribers receive recorded information via the

8—2072

subscribers' amplifiers $V_A$ sequentially in the line $A_1 \dots A_n$.

In $n$ cycles all the stored information of $mn$ bits is transmitted from discriminator $D_r$ to discriminator $D_{out}$ and from there to the subscribers.

We shall now discuss the principle of address selection (establishing the connection). To establish a connection between any two subscribers, the information received from subscriber $K$, recorded in discriminator $D_r$ and stored in the cores of the vertical row $K$, should be sent to discriminator $D_{out}$ to be stored in the vertical row $l$; information recorded in discriminator $D_r$ from subscriber $l$ (in the vertical row $l$) should be transmitted to the vertical row $K$ of the discriminator $D_{out}$. For this purpose the read-out pulse fed to bar $X_k$ of the discriminator $D_r$ should be followed by the preparation current fed to bar $X_l$ of the discriminator $D_{out}$ and vice versa. The bars are selected by the volatile memory with the help of decoder $D_1$.

The volatile memory has $m$ *storage cells* ($m$ conversing subscribers). The number of the subscriber is recorded in the cell corresponding to subscriber $K$, and vice versa. Storage cells are interrogated synchronously with the operation of distributor $D_x$ of the discriminator $D_r$. From the storage cell the code address is sent to decoder $D_1$ of the discriminator $D_{out}$. Volatile memory may employ magnetic cores. The subscriber's number arrives at the marker where first of all it is recorded in the intermediary discriminators and then sent to the volatile memory storage cell corresponding to the subscriber calling.

When a disconnect signal arrives at the volatile memory all the previously recorded numbers are rubbed out.

Whether the subscriber's line is engaged or free is determined automatically by comparing the number called with the numbers recorded in the volatile memory cells.

A description of the principle of operation of future devices handling information flows is given here with the single aim of illustrating possible ways of solving this important problem.

# Computer Elements in the Information Machines

## "Logical" Keys

A computer comprises a number of simple elements which perform logical operations with discrete signals.

The simplest of these elements, element $S$ (Fig. 33$a$), receives and stores one binary signal and transmits it to other elements of the device. The element may have several input circuits $A_1 \ldots A_n$ for the simultaneous reception of binary signals. A signal appears at the output of element $S$ (or $S_b$ Fig. 33$f$) with the arrival of an input signal. Thus the function of logical addition of input signals is being performed.

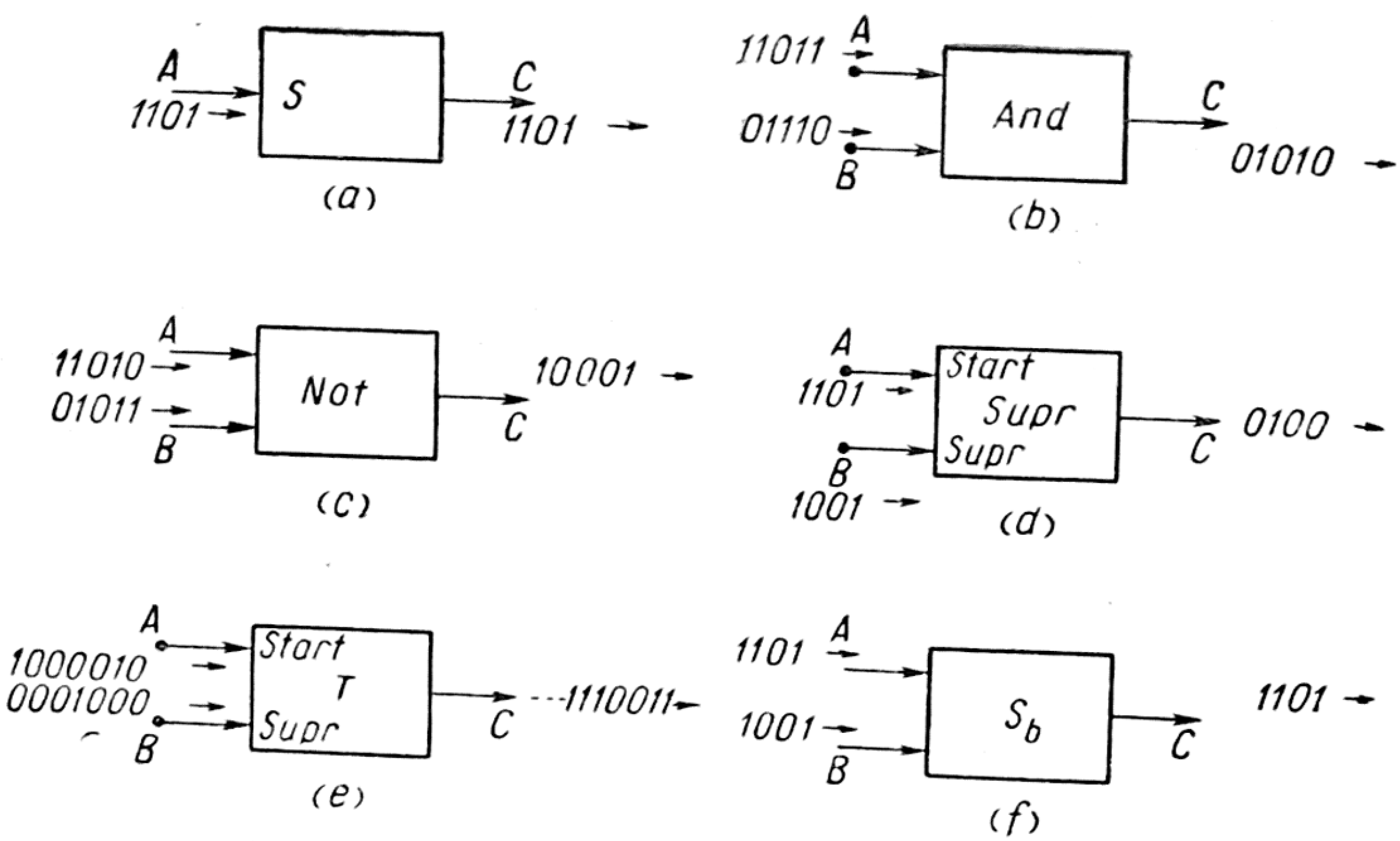



*Fig.* 33. Representation of logical functions

$A$ and $B$—key inputs; $C$—key output

The function "OR" can be expressed for two input circuits as follows:

| Signal at input $A$ | | Signal at input $B$ | | Signal at output $C$ |
|---|---|---|---|---|
| 1 | + | 1 | = | 1 |
| 1 | + | 0 | = | 1 |
| 0 | + | 1 | = | 1 |
| 0 | + | 0 | = | 0 |

Another logical element key AND (Fig. 33*b*) produces a signal at the output $C$ only when the signals 1 arriving at its inputs $A$ and $B$ coincide in time. The element AND functions as a logical multiplier of the information code signals since when a series of code signals arrives at its input $A$ and a series of other code signals arrives at its input $B$, resultant information appears at its output $C$ in which each signal is the result of the logical function "AND" (conjunction) with the corresponding pair of the information code signals $A$ and $B$.

The element AND can be used as a key in the binary information transmitting circuit from $A$ to $C$, its input $B$ being used for control. True, binary signals will pass via the element AND if the second input is excited by the code 1, 1 ... 1; as soon as signals 1 cease to arrive at the input, the element AND will no longer transmit information via circuit $AC$. Since inputs $A$ and $B$ act similarly any one of the two can be employed as the control input.

The unlikeness element or key NOT (Fig. 33*c*) adds up signal codes in modulus 2.

When a series of code signals arrives at one input, for instance $A$, of the element NOT and another series of signals at input $B$, the result will be the addition (in modulus 2) of each signal pair.

The element NOT can be used as an inverter (converter) of the incoming code signals. If we feed control signals 1 continuously to one of its inputs then at the output we will obtain information reverse to that arriving at the other input of the element. In the reverse information instead of the code signals 1 we will get the signals 0 and vice versa.

The key *Supr*, the "suppression" element (Fig. 33*d*), gates information from $A$ to $C$ without any changes; when the re-

striction signal is present in circuit *Supr* it ceases to gate information. There will be no signal at output $C$ when the inputs $A$ and $B$ are both 1. The input $B$ is said to be suppressing because when control signals 1 arrive at this input information is no longer gated along circuit $A-C$ via element *Supr*.

*Dynamic trigger* (*flip-flop*) $T$ is the element for memorising single bits of information (Fig. 33*e*). When only signal 1 arrives at its input $A$ a train of signals 1 appears at the output $C$, i.e., the flip-flop itself begins to generate the signals 1. These signals are reproduced at the trigger output until control signal 1 arrives at the input $B$ which stops the generation of the signals ("it cuts off" the flip-flop), and, instead signals 0, 0 ... 0 appear at its output. The flip-flop $T$ has two stable states—1 and 0. It begins to generate upon the arrival of one signal and stops generating upon the arrival of the others. The functions of the trigger inputs $A$ and $B$ are different (input $A$—triggering, input $B$—suppressing).

By using the set of logical elements discussed above we can realise a functional logical circuit of any complexity.

It should be noted that information passes through any of these elements with a certain time lag.

Information in the machine is expressed in discrete form, i.e., there is a definite time interval between any two code signals. Let us denote the time of passage of one coded signal and one interval (the code signal period) by $\tau$ and call it the machine operation cycle. Assume that the time lag (the time of operation) for all the keys and logical elements is equal to one cycle. Then the operation speed of the computer can be determined as the cycle time required for the processing of the given information by the given programme.

Cycle signals are fed to all the logical elements of the computer from the cycle signal source in the computer system.

Logical elements can employ electronic valves, crystal diodes and triodes, ferrite cores, etc.

Here is an example of the principle of operation of some of the logical elements employing multi-coupling magnetic circuits.

Fig. 34*a* shows the function "AND" circuit. The device is an original current transformer with a derived controlled

magnetic circuit $M$. On the left are three magnetic keys which sharply change the magnetic circuit 1, 2,.... 6 resistance under the action of the currents $i_1$, $i_2$, $i_3$. Alternating current with constant amplitude is passed via primary $w_1$. Voltage $U_{out}$, the value of which depends on the

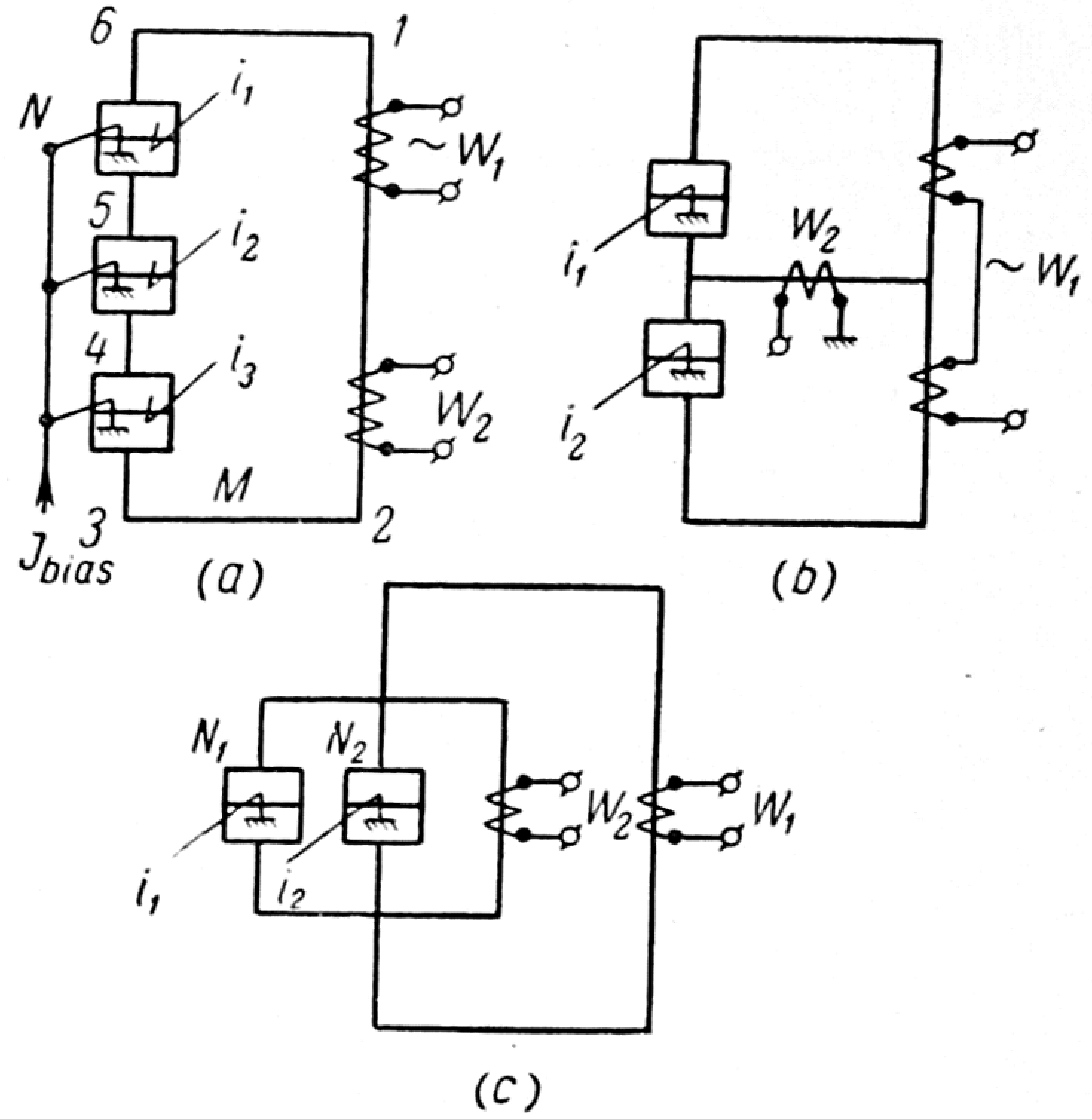



*Fig. 34.* Key diagram of magnetic keys performing logical functions

*a, c*—circuits performing logical functions *AND*; *b*—circuit performing logical function *NOT*; *N*—control cells; $W_1$—input winding; $W_2$—output winding; $I_{bias}$—bias current; *M* (1, 2, 3, 4, 5, 6)—magnetic circuit; $i_1$, $i_2$, $i_3$—control currents

total magnetic resistance of the magnetic circuit $M$, is induced in the secondary $w_2$.

Three control cells $N$ lie in the path of the magnetic lines of force. Each cell is a derived magnetic circuit with control windings on the middle bar.

The ferromagnetic material of the control cells $N$ can be saturated with the aid of the magnetising currents $i_1$, $i_2$, $i_3$ without affecting the rest of the magnetic circuit $M$.

Two cases of the operation of the device are discussed below.

1. All the three cells $N$ are premagnetised (saturated). The reluctance of each cell is very high, and voltage $U_{out}$ (0) induced in the secondary $w_2$ is so insignificant that it can be disregarded.

If signal currents $i_1$, $i_2$, $i_3$, creating ampere-turns equal in value and opposite in the direction to the magnetising ampere-turns $I_{bias}$, are fed to all the three windings of the cells, a signal appears in the transformer secondary $w_2$. Therefore, $U_{out}$ reaches its maximum value (1) only when

signal $i_1$,
and signal $i_2$,
and signal $i_3$ are present simultaneously.

This corresponds to the logical function "AND" (logical multiplication).

2. All the three cells are not premagnetised and the reluctance of each cell is low. If one of the control currents is then fed to the windings, one of the cells will possess high reluctance and the output voltage will be small.

To obtain the signal at the output all three control currents should be absent, i.e., there should be

neither current $i_1$,
nor current $i_2$,
nor current $i_3$.

This is also used to indicate no-signal state.

To cut-off the output voltage $U_{out}$ the presence of one of $i_1$, $i_2$, $i_3$ is quite sufficient.

In some cases it is required that the device produces a signal only when one of the two signals $i_1$ or $i_2$ is present, and not when both signals $i_1$ and $i_2$ are present (the operation of logical addition in modulus 2 performed by the element NOT).

Fig. 34*b* shows circuit of such a unit. No voltage is induced in the secondary $w_2$ when currents $i_1$ and $i_2$ act simultaneously due to the opposing magnetic fluxes created by the primary current; the output signal appears when one of the control currents is absent. Therefore, the signal appears when there is

either $i_1$,
or $i_2$,

and the signal is absent when both $i_1$ and $i_2$ are acting.

The unit performing the operation does not require presaturation (i.e., it operates without bias ampere-turns or without permanent magnets creating the bias field).

Shown in Fig. 34*c* is the circuit without bias for the function "AND".

The secondary $w_2$ is located on the bar placed parallel to the control cells $N_1$ and $N_2$. In the absence of any of the two signals, cells $N_1$ and $N_2$ play the role of magnetic shunts for the secondary bar; therefore low voltage is induced in the secondary. When control currents appear in the cells their reluctance sharply increases and the magnetic flux passes on the whole through the bar of the secondary in which maximum voltage is induced.

Thus the unit performs the function "AND", i.e., to obtain the maximum value of the secondary voltage there should be

signal $i_1$

as well as signal $i_2$.

It is quite natural that the above logical functions can also be performed in separate multi-winding cores.

Logical elements are combined into sections and sections into units intended for performing operations (for instance, collation, addition, subtraction, shifting, conversion, reading off, decoding, etc.).

## Computer Units and Circuits

Discussed below are some of the circuits and units employing logical elements and performing definite logical functions and arithmetical operations.

Fig. 35 shows the *addition circuit*. Numbers in binary code are added up in series as follows. The digits of the number in binary code go sequentially to the adder, storing on the right. The digital codes of each number arriving at the outputs $A$ and $B$ are sequentially compared at elements AND and NOT of the first and second stage of comparison. Upon the arrival of 0 and 1 the result goes to the second stage via element $\text{NOT}_1$. The result goes to the second stage via element $\text{AND}_1$ upon the arrival of two signals 1. In the second stage the result which arrived from the first stage is com-

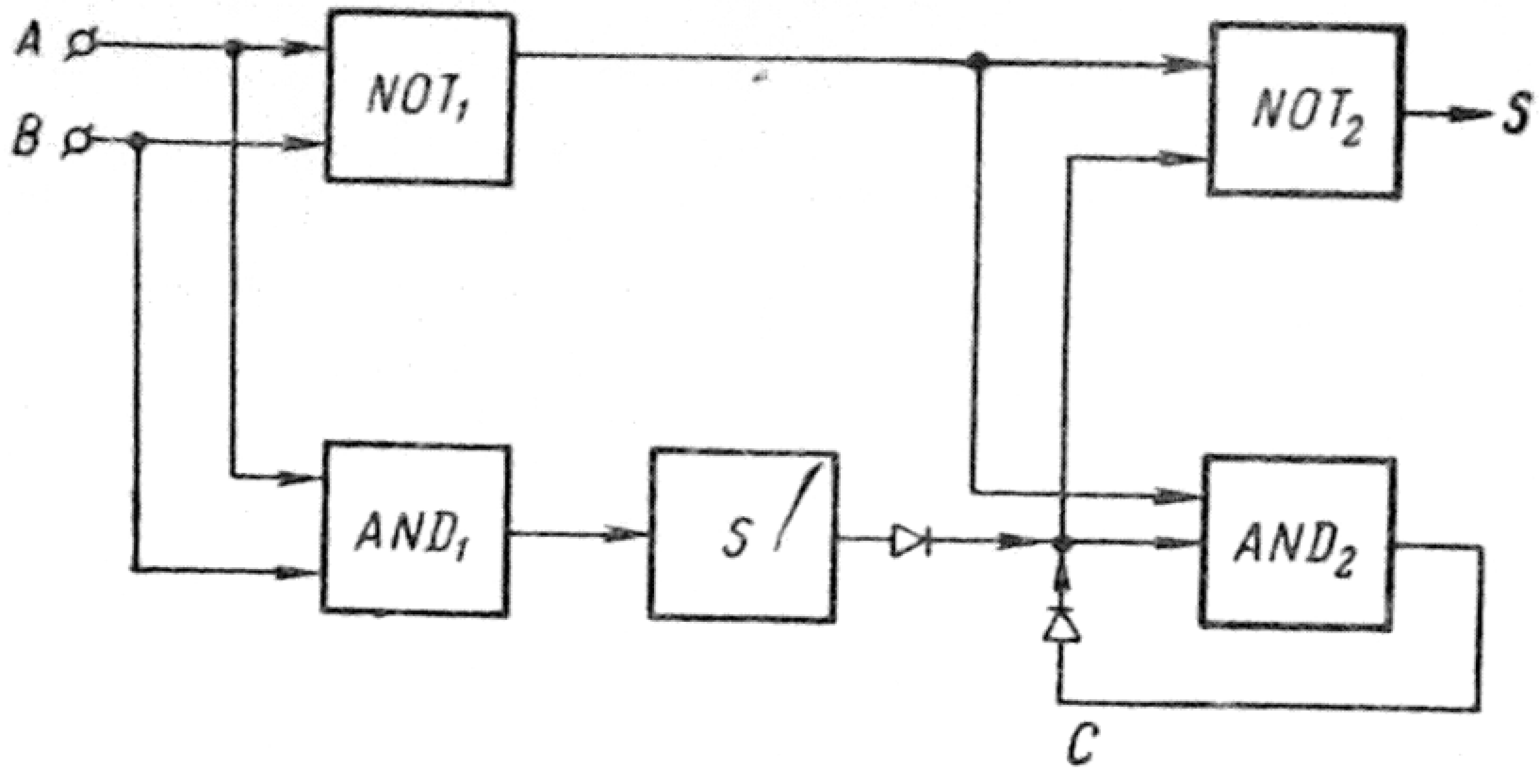



*Fig. 35.* Adder

*A* and *B*—input of numbers being added; *C*—sum output

pared with the previously stored result (the carrying of units from row to row on line *C* being taken into account).

The summing up section adds up multi-digit positive numbers. To add up algebraic numbers an additional unit has to be introduced which converts negative numbers into positive: the so-called inverter (Fig. 36). The digit code arrives at the input *A*. The sign code of the number arrives first and then comes the number itself, beginning with the digit on the right.

The moment the number goes through the element AND a signal is fed to it from the control unit via line *B*. If the number is negative the element AND operates and flip-flops the trigger *T* to produce the inversion signal. The digit number passes via element NOT with signals 1 arriving

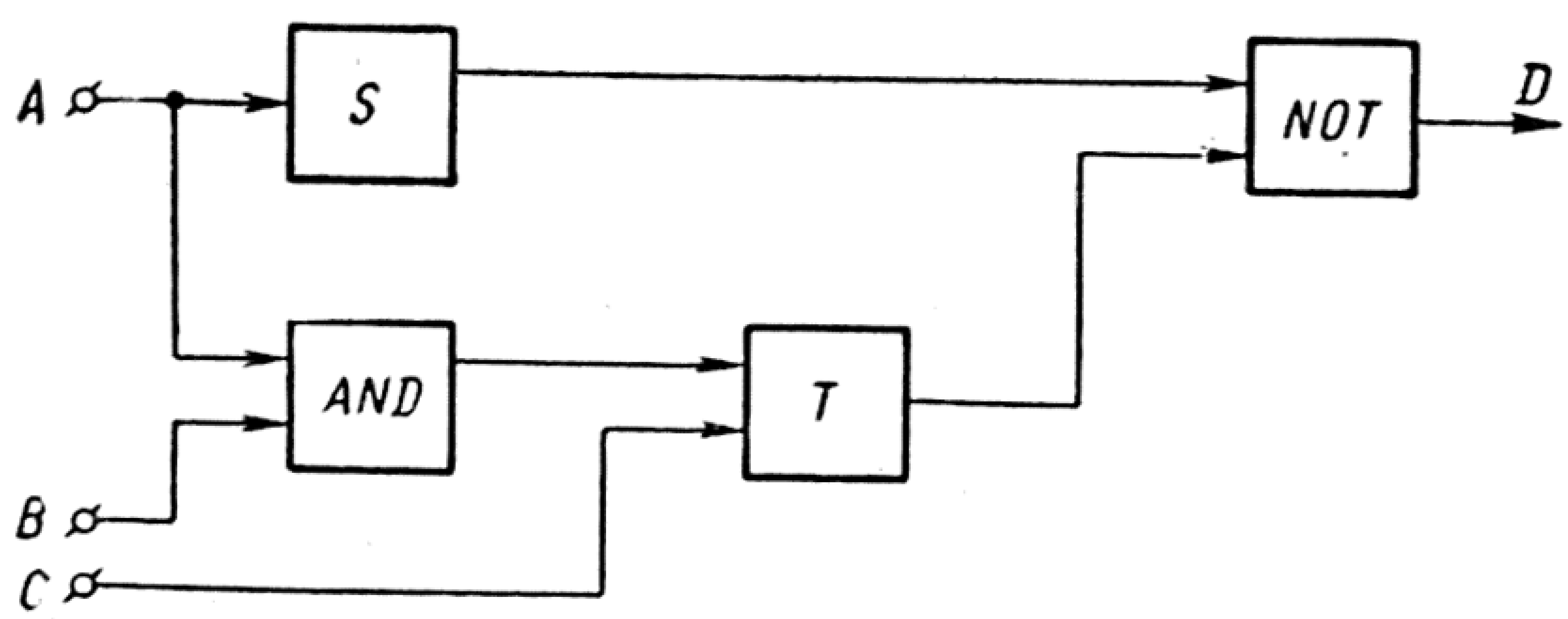



*Fig. 36.* Inverter

*A*, *B* and *C*—inverter inputs; *D*—inverter output

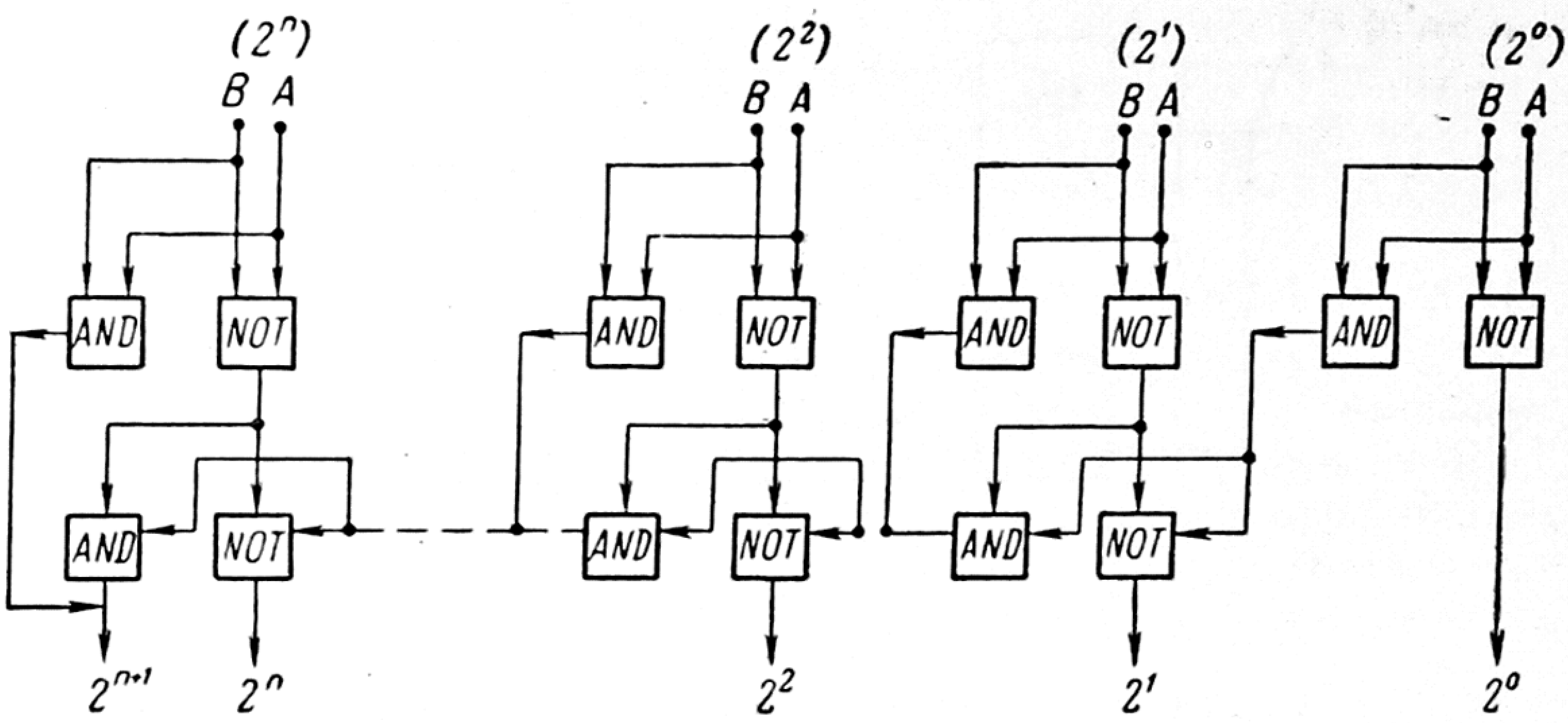



*Fig. 37.* Parallel adder

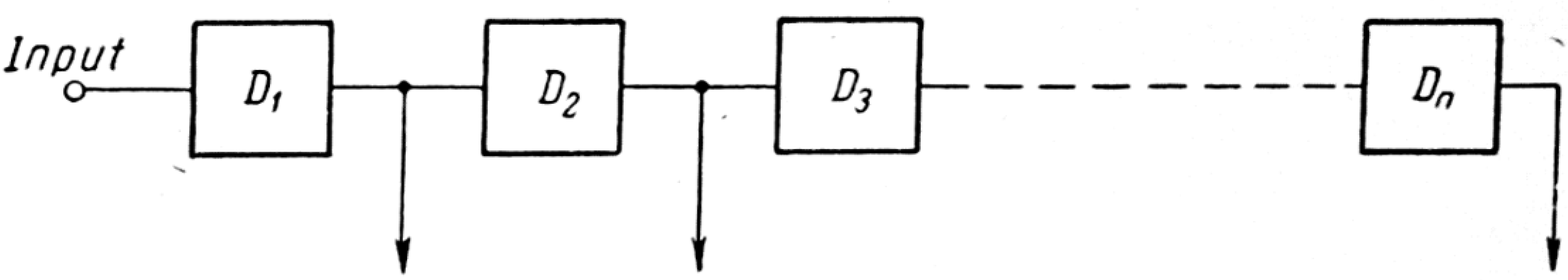



*Fig. 38.* Binary counter

at its second input from the trigger $T$. A reverse digit code is obtained at the element NOT output, i.e., 0 instead of 1 and 1 instead of 0. The digit number goes through element NOT without any changes due to the one-cycle lag in the trigger operation of the trigger $T$ which is controlled via line $C$. For additional information signal 1, coinciding with the number categories following the first smallest unit, is fed to the input $B$.

If a positive digit code beginning with zero arrives at the inverter, it goes through element NOT without any changes (direct code) since the trigger $T$ is not actuated.

Given in Fig. 37 is the key diagram of an adder for parallel simultaneous addition. Elements AND and NOT serve to determine the category of each sum. Assume that elements AND of the second row operate practically instanta-

neously. If element NOT operates the sum (1) appears at the output. If element AND operates the transfer signal is transmitted to the elements of the next category as shown in the figure.

Counters are used to count code signals 1 in the processed information.

The binary counter cell $D$ (Fig. 38) counts off two pulses arriving at its input. After every second pulse it transmits a carry pulse to the neighbouring cell. Every subsequent cell counts off pulses in a larger category than the previous cell. Thus, for instance, cell $D_1$ counts off the pulses in category $2^0$ (units), cell $D_2$ counts in category $2^1$ (twos), cell $D_3$ in category $2^2$ (fours), etc. Cell $D_n$ counts off pulses in category $2^{n-1}$.

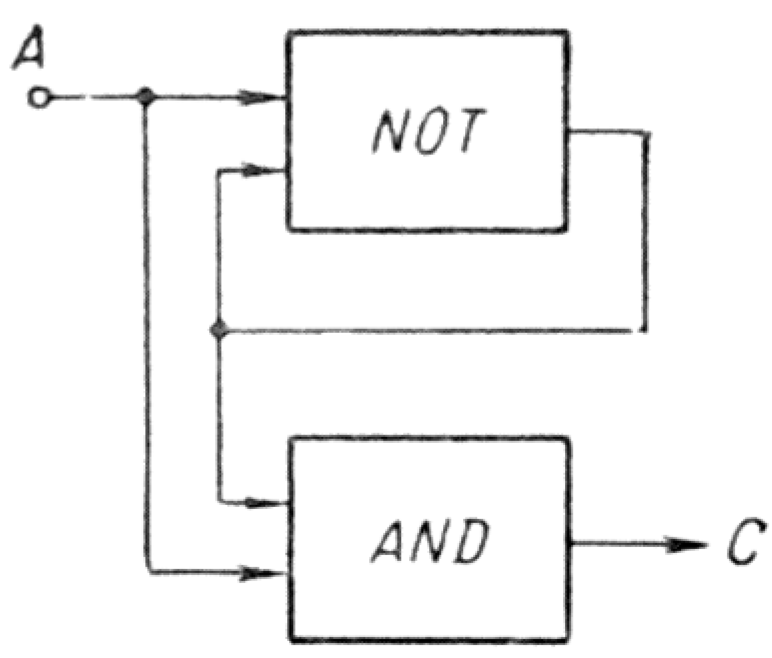



*Fig. 39.* Binary counter cell
$A$—input; $C$—output

Fig. 39 presents a diagram of the binary counter cell, consisting of the elements NOT and AND. The element NOT is provided with a feedback from output to input. When signals arrive at the input $A$, signals corresponding to each second code signal 1 appear at the output $C$. The binary counter can also be used as a frequency divider of cycle signals by $2^n$. Triggers $T$ can be used in cells $D_2$, etc., instead of NOT.

The code arriving at the counter input is consecutively divided by 2. If $n$ signals arrive at the input, then $n/2$ signals appear at the output of the first cell $D_1$, $n/4$ signals at the cell $D_2$ output, etc.

The dynamic trigger $T$ chains are used to construct decimal and in general $n$-cimal systems of counters, distributors and commutators (Fig. 40).

The triggers are divided into two groups—even and odd—controlled through two different channels by sending the suppression signal to an even or odd group.

The triggers are chain-conducted in series, the number of the counter-off code pulses being determined by the number of the trigger operating in the chain. Code pulses arrive at

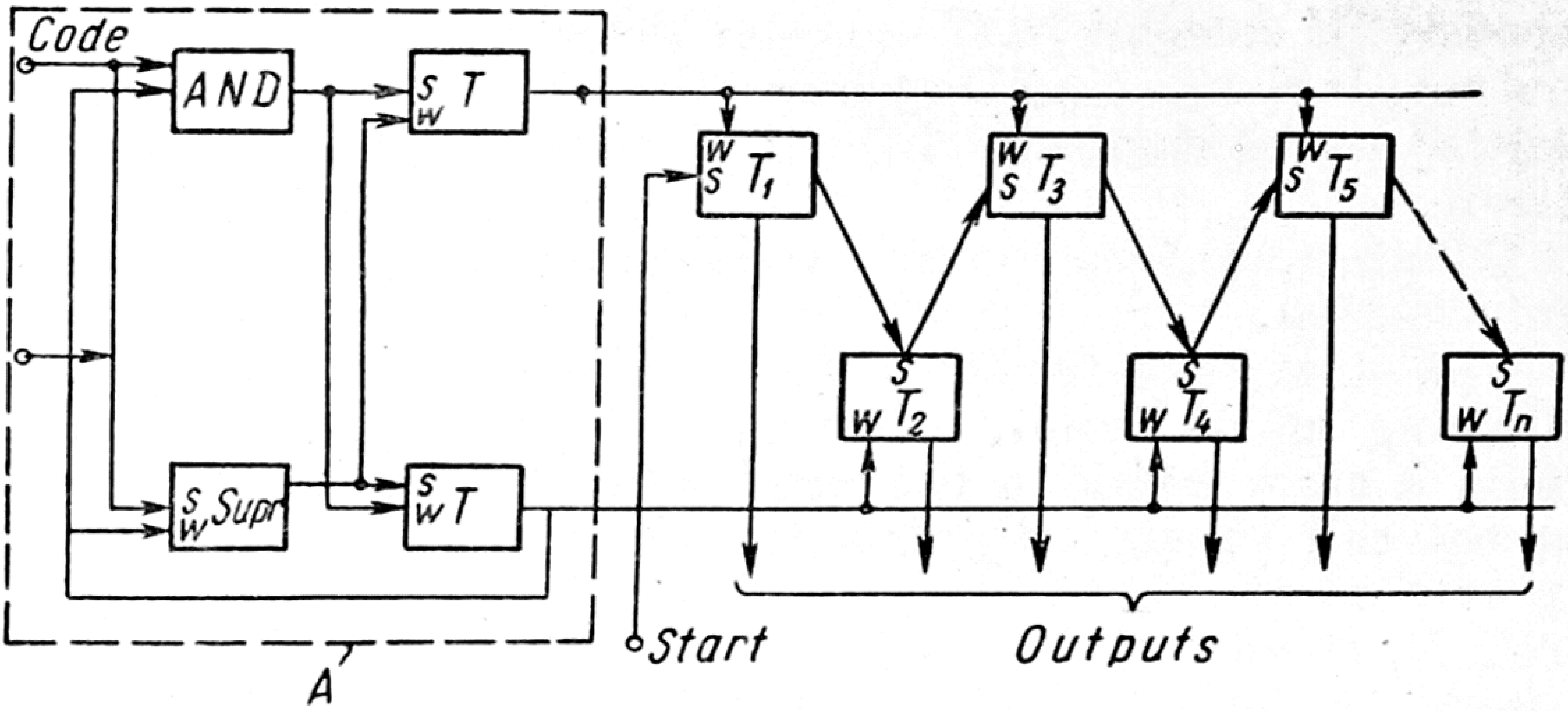



*Fig. 40.* Trigger chain
*s*—triggering winding; *w*—suppression winding

the input of the trigger circuit *A* which feeds signals to odd and even groups.

The control trigger circuit *A* can be used as an independent unit distributing signals in two directions.

The chains comprising the dynamic triggers can be used as distributing or commutating units.

The logical function of *code comparison* can be carried out by the device shown in Fig. 41.

Code signals of one bit of information arrive at inputs $A_1$, $A_2$ ... $A_n$ of elements NOT and simultaneously code signals of another bit of information arrive at inputs $B_1$, $B_2$ ... $B_n$. There will be no signal 1 at either of the element NOT outputs when all the compared code signals match; the

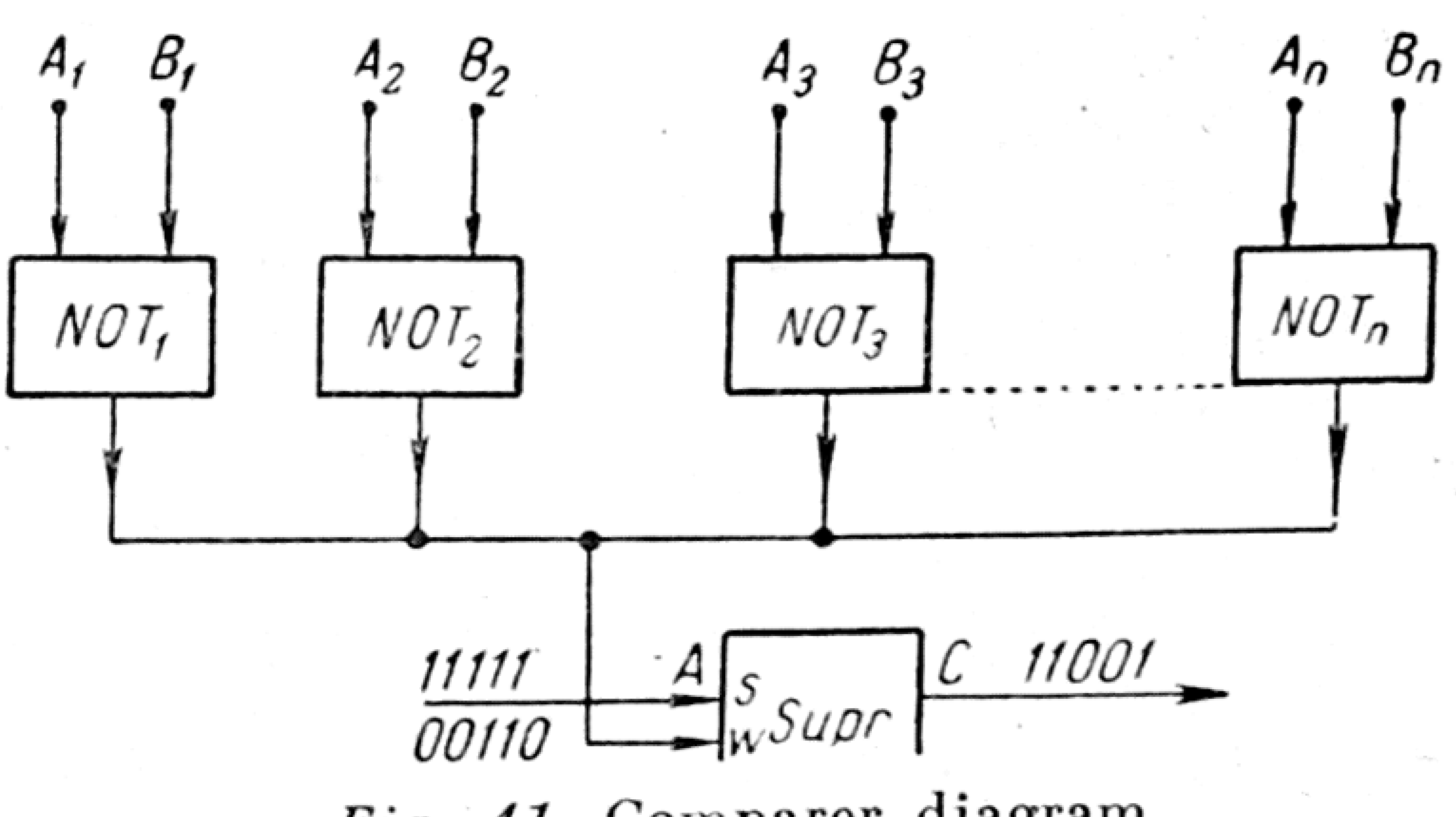



*Fig. 41.* Comparer diagram
*A* and *B*—inputs of numbers to be compared; *C*—output

signal 1 will appear at the output of one of the elements NOT even if a single code signal of one bit of information does not match with the corresponding signal of another bit of information. If a control signal is fed at the same time to the input $A$ of element *Supr* then in the first case it passes through the element and a "matching" signal appears at the output $C$. In the second case there will be signal 1 at the suppression input of the element *Supr* and the control signal will not appear at the output $C$; this indicates that the information codes do not match. As a result of comparison of several pairs of numbers a code appears at the output $C$ in which 1 corresponds to the matching pair and 0 to the mismatched one.

Fig. 41 shows the comparer circuit for the case when the code signals fully match.

Sometimes it is necessary to change the position of the code signals in the information (to shift the entire information left or right, this being tantamount to multiplying it $2^n$ or by $2^{-n}$). In this case a special device called a shifter can be used. Its key diagram is shown in Fig. 42.

The shifter is a controlled matrix of ferrite cores on which any $n$-category binary code can be recorded. The code is recorded diagonally along the entire matrix. The initial $n$-category code is recorded on each line with a shift of one

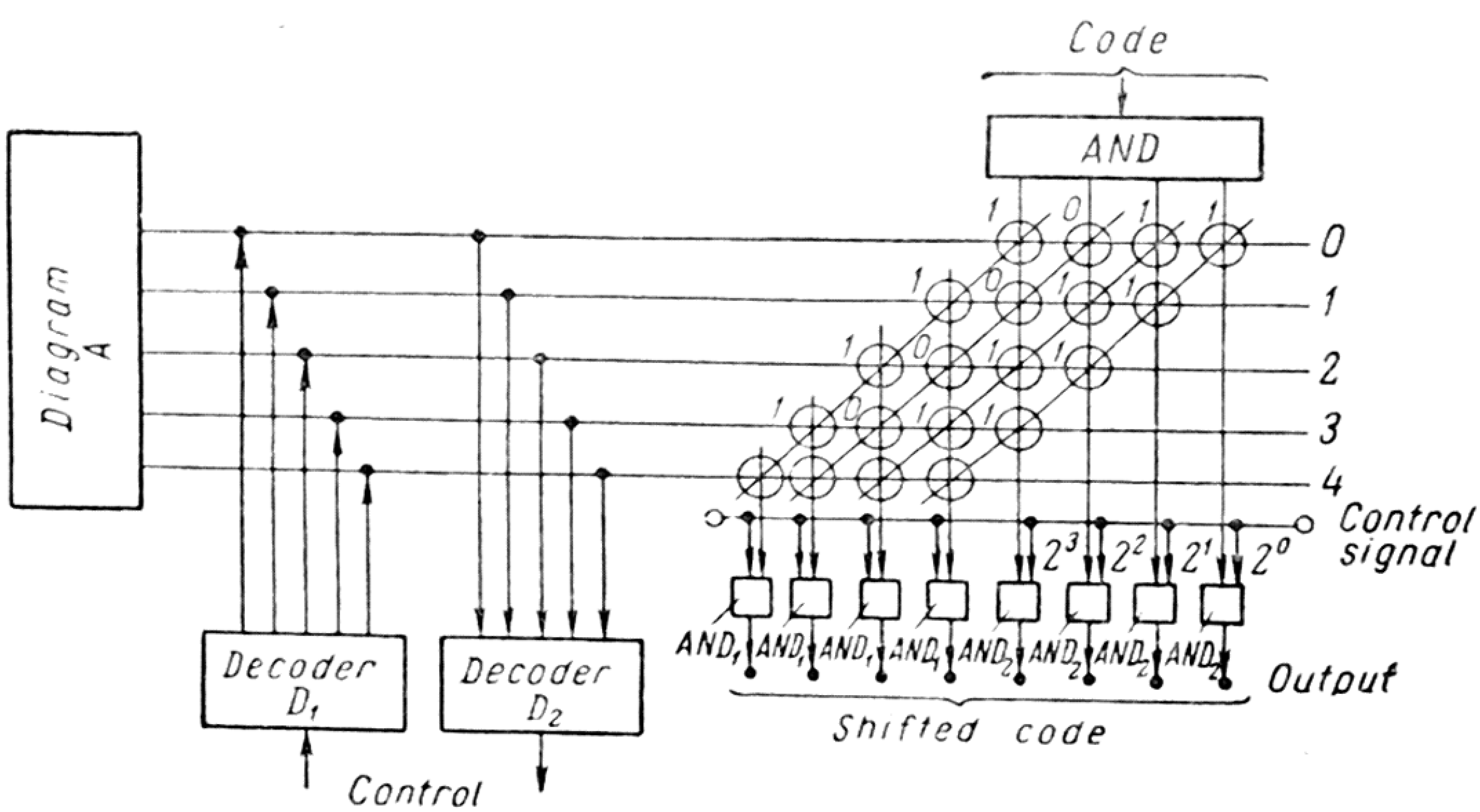



*Fig. 42.* Shifter diagram

category. The number of lines of the matrix is $n+1$, the number of columns $2n-1$. The initial $n$-category code shifted left or right by any number of categories can be obtained by retrieving (reading out) the corresponding line of the matrix.

The read-out code arrives simultaneously at all the output keys AND, while the control unit selects the required group of these keys.

The read-out signal arrives at the line of the matrix from decoder $D_1$ or from the shifter control circuit $A$.

The matrix lines can be read out in a definite sequence and controlled by the code number recorded in the shifter control circuit $A$. Beginning from the top the machine will consequently read out those lines of the matrix for which code signal 1 was recorded in the corresponding location of the circuit $A$.

Upon the arrival of the read-out signal, decoder $D_2$ presents in binary code the number of the line being read out.

*Example*. Recorded on the matrix in Fig. 42 is the code 1011. If the read-out control signal is fed to the third line from top and the control signal to keys AND$_2$ we shall obtain the code 1100, i.e., the initial code shifted left by two categories.

The information machine computer comprises separate functional units which in their turn consist of logical elements. Each logical element functions under the action of the control signals arriving from the conrtol system.

Any complex logical or arithmetical operation to be carried out with the selected information (comparison, analysis, synthesis, etc.) can be reduced to a number of elementary operations which boil down to gating control signals to certain elements of the system. If we assume that gating corresponds to code signal 1, and the absence of the signal to 0, then the distribution of the control signals can be recorded as a definite combination of code signals and this can be regarded as distinctive information (a command code).

An operator drawing up an algorythm for the searching and processing of information expresses it as a sequence of elementary operations. There is no need to write down the sequence of elementary operations for each logical element of the system. The distributing system inside each unit of

the computer will automatically send pulses to each controlled element of the unit at the right moment. After the operator selects it the given unit begins to operate automatically. This kind of distribution system controlling the unit is called local programming.

Assume that the local programme is a small-capacity long-time memory with code signals for carrying out a certain operation recorded in the memory cells with the help of coupling elements. The memory is automatically controlled by the distributor which selects the cells one after the other.

Each output of the memory cells is connected with one control element of the unit. When the programme is read out, only those control elements operate at each cycle which receive code signals 1.

When units are employed in a computer an operator should only write down the sequence of major operations (commands).

The sequence of operations written down in code for the solution of a problem is called a programme. The programme is converted into binary code and recorded in the machine memory just as the usual information is recorded.

Here is an example of how the following operation is recorded and carried out: compare information in the machine memory address $A_1$ with information recorded in the address $A_2$, count the number of matching attributes and send the result to the volatile memory address $A_3$.

The simplified programme of operation can be recorded in the following sequence:

1. retrieve information from the machine memory first from address $A_1$, then from address $A_2$;
2. compare the retrieved information in unit $X_1$;
3. when each of the attributes match send one pulse $C$ to the counter unit $X_2$ (add up the number of matched attributes);
4. send the results to address $A_3$.

Accordingly, the programme should have two commands:

1. compare $X_1$, $A_1$, $A_2$;
2. count $X_2$, $A_3$.

If we assume that the operation "compare $X_1$" has the binary code 101101, "count $X_2$"—000101, and the addresses

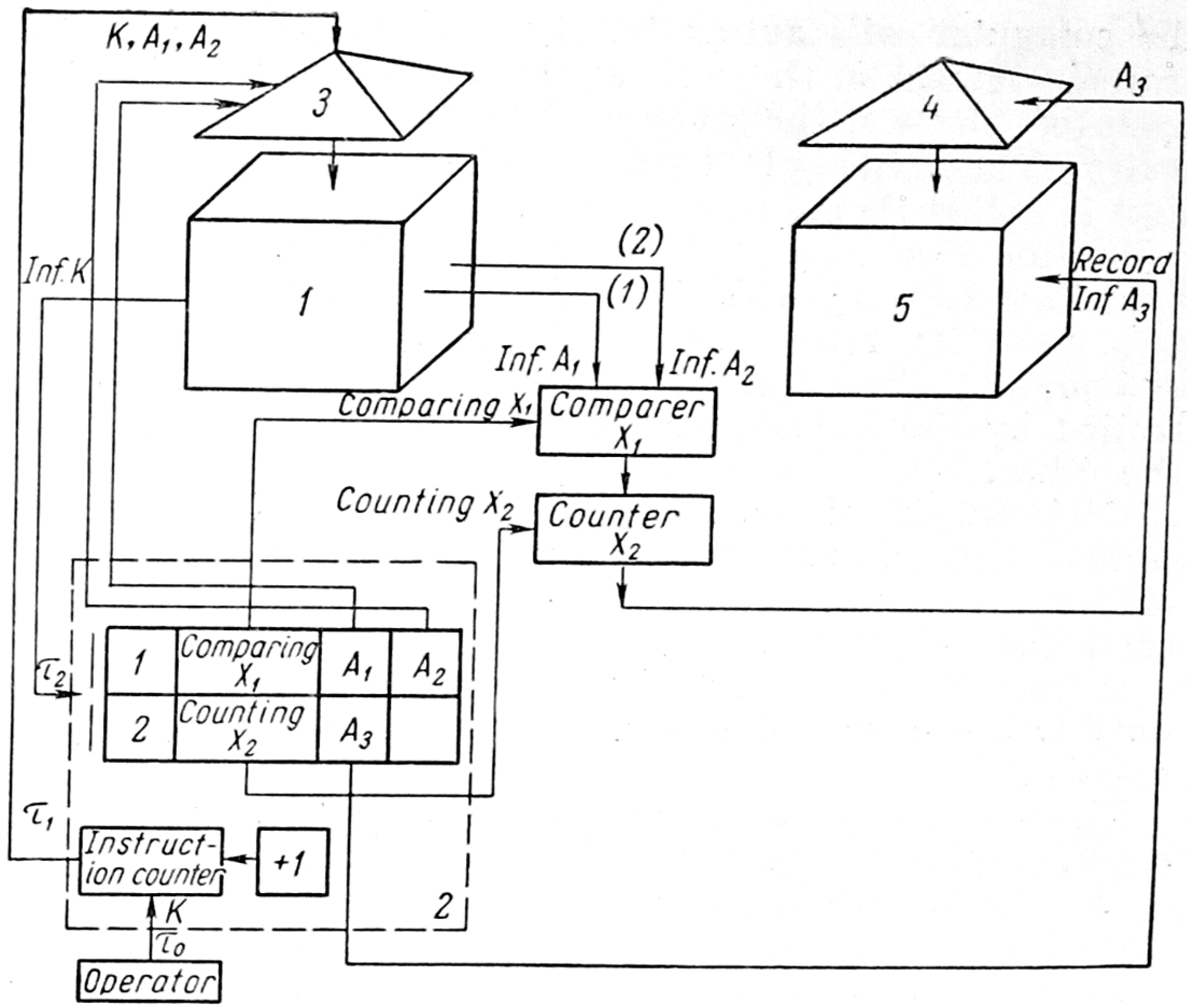



*Fig. 43.* Block diagram of comparing and counting operations

*1*—long-time memory; *2*—control unit; *3*—long-time memory decoder; *4*—volatile memory decoder; *5*—volatile memory

$A_1$, $A_2$ and $A_3$ 1100001010, 0011011010, 0000000010, respectively, then the programme will be recorded in the machine memory as follows:

1. 101101, 1100001010, 0011011010,
2. 000101, 0000000010.

Fig. 43 illustrates the functional diagram of the above operations. The programme is recorded in the machine long-time memory as the command code arrives at the control unit one command after the other. The command "compare $X_1$, $A_1$, $A_2$" arrives first. It is decoded and broken down into parts referring to the operation code and to the addresses.

The address $A_1$ code is transmitted to the decoder 3 of

the corresponding memory unit, with information ($Inf\ A_1$) read out from this address. The information arrives at the comparing unit $X_1$, the input of which is opened by the operation code "compare $X_1$" ($X_1$ plays the role of the comparer address).

Each command should have the following codes:

1. the operation number in the given set of operations (system of commands);

2. the machine memory cell addresses from which information can be retrieved;

3. a volatile memory cell address to which the result of the operation should be sent. Then the address $A_2$ code is fed to the decoder *3* and the information recorded in the cell with the address $A_2$ ($Inf\ A_2$) is read out from the memory. This information also goes to the comparer $X_1$.

The code "compare $X_1$" not only actuates the unit $X_1$ inputs but also switches on the distributor of the local programming of this unit. Control signals are fed at definite moments of time to separate logical elements of the comparer $X_1$ and the unit compares $Inf\ A_1$ with $Inf\ A_2$. After $Inf\ A_1$ and $Inf\ A_2$ are selected and the comparer $X_1$ begins to compare them, the second command, "count $X_2$, $A_3$", arrives at the control unit *2*. The counter $X_2$ is actuated (its input is ready to receive matching signals $C$ and counting proceeds according to the local programme).

Address $A_3$ is memorised. The counter $X_2$ counts off every arriving matching signal. As a result, when the unit $X_1$ has finished comparing the information a certain number will be recorded in the counter $X_2$. This number is the outcome of the operations performed, or in other words it is the information which should be recorded in the operative memory cell at the address $A_3$ ($Inf\ A_3$).

From the control unit the address $A_3$ is sent to the decoder *4* of the volatile memory *5* and $Inf\ A_3$ is recorded in the memory.

The control unit *2* containing the so-called command counter consequently retrieves commands from the memory. The cell memory addresses with commands recorded in them are automatically set in the command counter. The entire programme of $n$ commands takes up $n$ memory cells.

At the beginning of the operation the operator sets up

in the command counter the address of the memory cell in which the first command is recorded (address $K$).

The command counter is coupled with the address decoder and retrieves information at the address $K$ (*Inf* $K$). After each command set at the counter has been carried out, the number automatically increases by one unit, and information *Inf* $K$ is retrieved from the next memory cell ($K+1$, $K+2$ ... $K+n$).

Given below is a particular example to illustrate some of the principles of programme control.

The machine in our example (Fig. 44) comprises four major units: 1. machine memory (magnetic volatile memory MVM and long-time large-capacity memory LTM); 2. control unit CU; 3. arithmetical unit (computer) with internal memory employing multiple discriminators *AU*; 4. external equipment *EU* for data input and output.

Information (in this case, code numbers) goes from the memory unit to the arithmetical and output units and back again via three code bars $B_{read\text{-}out\,1}$, $B_{read\text{-}out\,2}$, and $B_t$. The first two bars receive information selected from the memory and are called read-out bars and the third bar $B_t$ (transmitting bar) transmits information to the magnetic volatile memory. The information is the result of the operation carried out in the *AU* with the two series of code signals arriving from the memory via $B_{read\text{-}out\,1}$ and $B_{read\text{-}out\,2}$.

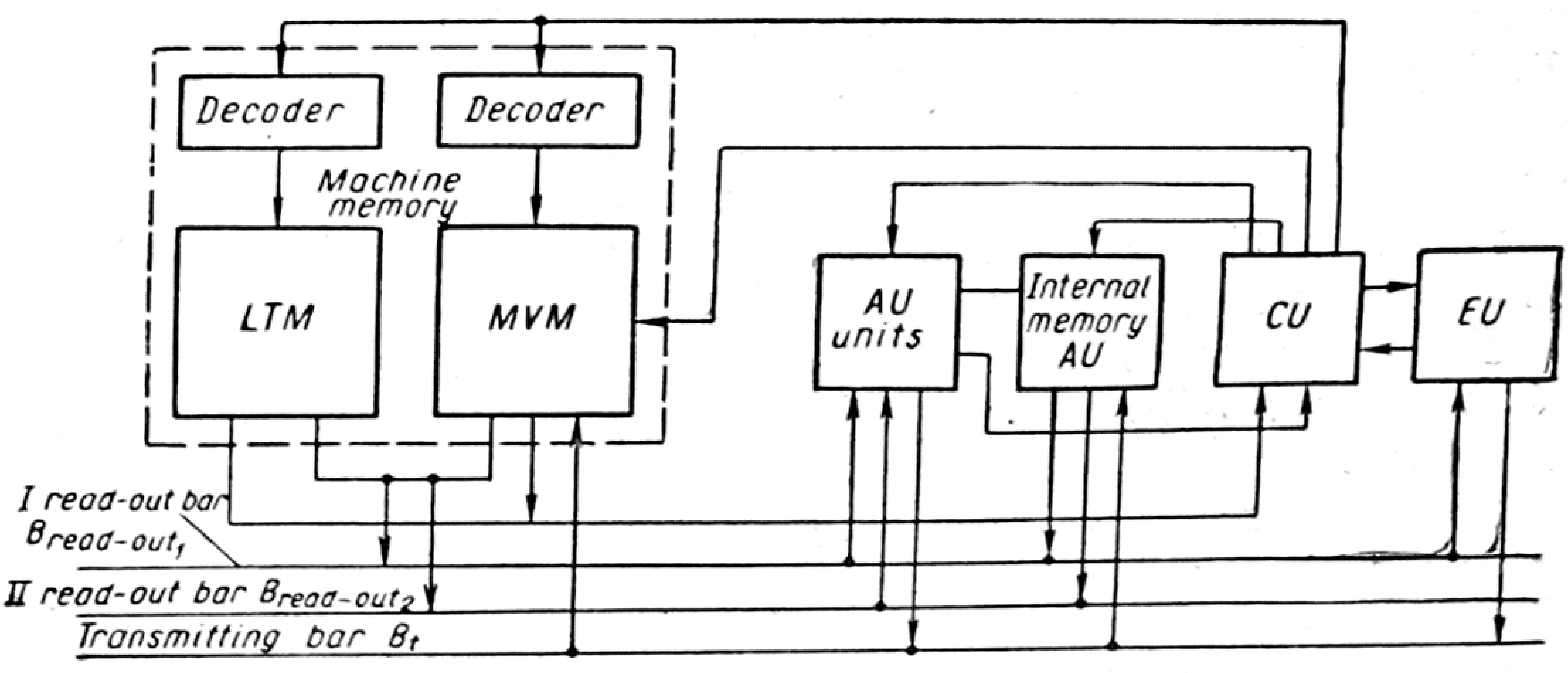



*Fig. 44.* Block diagram of a machine employing capacitive and magnetic memory elements

The internal memory in the arithmetical unit makes it possible to cut down the number of interrogations sent to the main machine memory.

The operational cycle includes: selection of the operation component, performance of the command itself, and sending the results of the previous command.

The time required by the machine to carry out any one operation (command) is called its operational cycle. The usual cycle includes carrying out the prepared command, selection and preparation of the next command and making up the number of the next command to be selected in the next cycle.

It takes the machine different times to complete each operational cycle, but the time is always a multiple of the cycle.

There are single-cycle operations (for instance, addition, logical multiplication, control, etc.) and multi-cycle ones (multiplication, shifting, normalising, division). Besides there are special slow operations of inversion with input and output units.

Operations performed by the machine can be divided into four groups.

*Logical operations, comparing, and operations with scales*: logical addition, subtraction, and multiplication, comparing for matching, comparing for "more", for "less", adding or rubbing out a unit in the $n$-th word category, adding or rubbing out all the units on the right or on the left of the $n$-th word category; finding an association by the given combination of attributes; finding a new chain of associations by the terminal ones.

*Arithmetical operations*: addition, subtraction, accumulation, multiplication, division, code adding, operations of shifting and normalising.

*Control operations*: transfer of control (conditional and unconditional) with the location of transfer being memorised, return (conditional and unconditional) to the memorised address, recording the numbers in the modifying discriminator for recirculation, end of cycle comparison, stopping the machine.

*Input and output operations*: pack operations of printing on and reading off the punched tape, printing, operations with magnetic tape.

9*

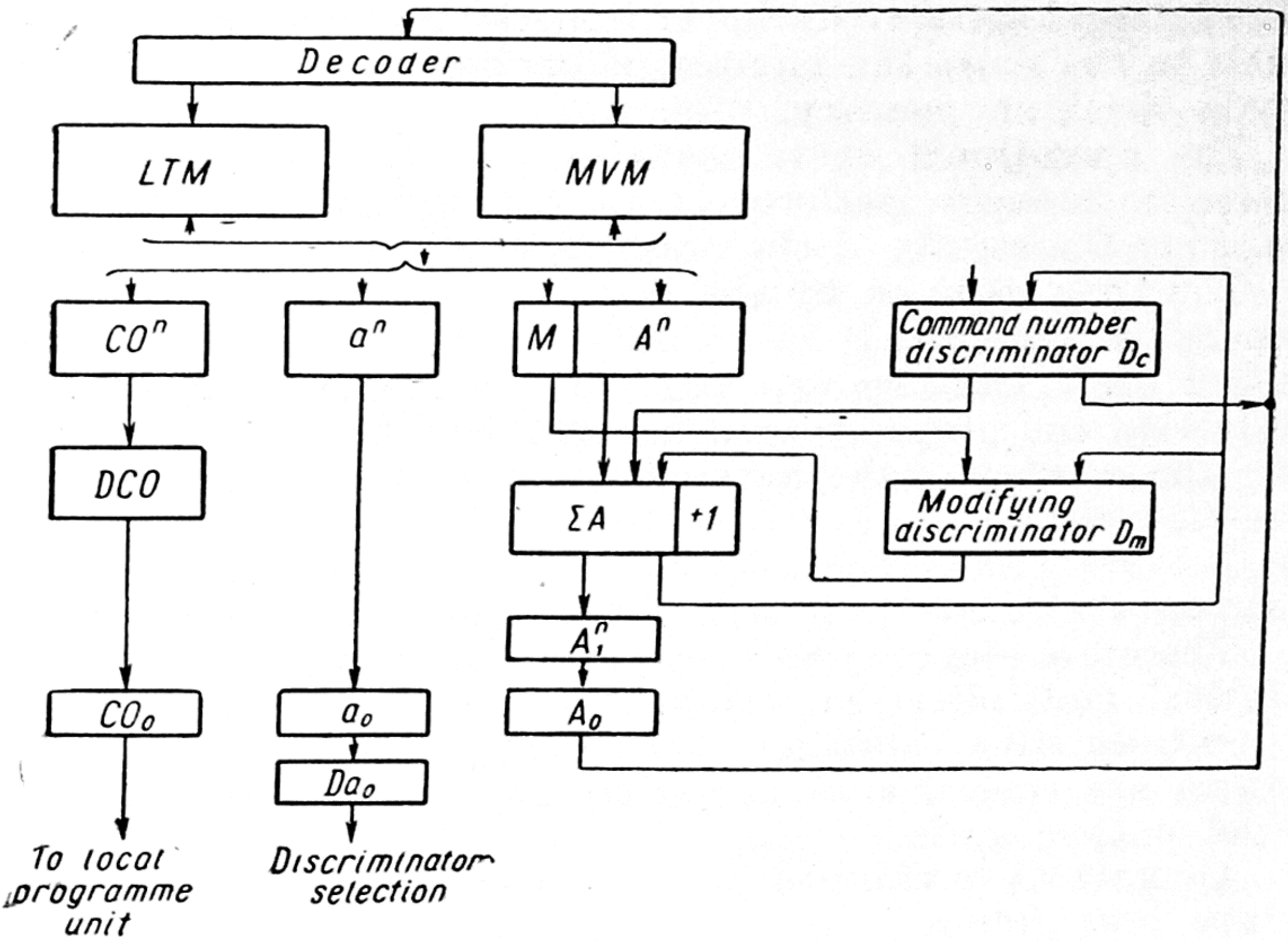



*Fig. 45.* Block diagram of the machine control unit

The first and second groups of operations are performed in the machine arithmetical unit. Control operations are performed in the control unit itself. Input and output operations are carried out by special equipment.

The arithmetical units have their own control units included in their circuit. Each unit performs a definite range of operations and in the process produces its own control signals.

Since there are several self-contained units in the arithmetical unit they can operate in parallel.

The central control unit of the machine comprises two units; the command pre-discriminator and the main discriminator (its block diagram is given in Fig. 45). At the beginning of the operation the first command is retrieved from the machine memory located at address $K$. The command is fed to triggers $CO^n$, $a^n$, $A^n$ of the command pre-discriminator.

The instruction is divided into three parts: operation code $CO$, the inner memory $AU$, cell address $a^n$, and the so-called "long" address $A^n$ (the address of the cells of the machine memory $MVM$ and $LTM$).

The operation code is memorised and decoded by the decoder $DCO$.

The "long" address $A^n$ contains an attribute $M$ indicating that while the given operation is being carried out the address should be changed by some number $m$ recorded in the discriminator $M$.

Address $A^n$ arrives at the address adder $\Sigma A$ where it is added up with the content of the discriminator $M$ or with zero (depending on the presence of the attribute $M$). The result is memorised by the triggers $A_1{}^n$.

Moreover, the command pre-discriminator has the instruction number of the discriminator in which the number of the memory cell $K$ containing the command is set at the start of operation. The memory units are interrogated with the help of the command number discriminator which sends the number recorded in it to the $MVM$ and $LTM$ address decoder.

After the first command is retrieved from the memory the content of the command number discriminator (number $K$) goes to the address adder $\Sigma A$ where a unit is added to it. Thus a new number—that of the second command—is formed which is memorised by the command number discriminator. Here ends the preparatory cycle of the machine operation.

After that the prepared command is received by the main command discriminator which memorises it for the time of operation (for one cycle). Depending on the decoded operation code a control signal is sent to the local programme of the selected machine unit. Memory cells with the required numbers recorded in them are selected by the address of the internal memory cells and by the "long" address. The address $a_0$ decoded in the decoders $Da_0$ controls the selection of one of the multiple discriminators of the arithmetical unit internal memory, while the "long" address $A_0$ goes to the address decoder $MVM$ and $LTM$.

Thus the machine memory $MVM$ and $LTM$ is interrogated twice during a single operational cycle, once for the instruction (in the cell with number $K+1$), and the second

time for the number (in the cell with number $A_0$). Sequential retrieval of instructions is ensured by adding one unit to the command number at each operational cycle.

The above principles of programme control ensure the interrogation of any machine memory cell or of the arithmetical unit internal memory for information and its processing according to any of the above-listed operations.

Such a machine is capable of solving a wide range of problems.

The list of operations performed by the machine even for a very limited scope of information problems should be extended by introduction of by-word analysis and synthesis, as well as by special operations which will permit the application of machine memory units with a larger volume of information.

When constructing information and logical machines which can handle a rather limited range of tasks, use can be made of the principles of control, decoding and information retrieval described above.

However, already at the very first stage the computing unit will differ in its principle of operation from conventional computers first of all by its greater volume of processed information, and also by the presence of the associative memory, automatic dictionaries and other units which we have discussed above.

Comparing a large number of attributes, shifting, operations with scales (inserting and erasing a code signal at a certain address location) as well as operations connected with the associative search will be the main features of information processing.

In the general case the computing unit of an information machine will be a multi-channel system simultaneously processing the information connected with many interrogations.

In some of the operational cycles the one channel processing information receives and decodes the command, interrogates the long-time memory, receives information from it and processes this information. Since the speed of information reproduction from the long-time memory is very great (scores of thousands of information cells per second) while the speed of the logical processing is rather small in many cases, the distributors scan all the other channels while information

is being processed in one channel, taking information to them from the long-time memory. Thus the overall number of channels taking part in the information processing is determined by the time necessary to carry out one elementary operation of information processing (a cycle).

For example, if we assume that one operational cycle is equal to 10 time cycles then the central distributors can serve 10 information-processing channels (the distributors can be for instance packet-by-step discriminators).

Each information-processing channel comprises a logical unit performing logical operations and by-letter comparing, an arithmetical unit performing operations required by the processing counter unit, a volatile memory and input and output units.

If the programme of answering interrogations is appropriately organised, all the information pertaining to the given attributes can be compared in parallel with the information retrieved from the machine memory. Multi-category units possessing the functions of logical addition and multiplication should be envisaged for this purpose in the computing unit. To carry out parallel simultaneous comparing these units can for example be of the matrix type. The comparing speed of these units will be determined by the speed of information retrieval from the memory and consequently will be very great.

In some cases the information machine is a system of combined electronic machines of narrow specialisation with automatic exchange of the results of pack operations and of the programmes. This trend marks the initial stage in the development of the information systems. There is a system, for example, comprising three machines, of which one is a high-speed machine, the other one controls and encodes programmes and the third one retrieves information from external stores, sorts it and performs other preliminary search operations. A general control is used to coordinate and transmit information in order to ensure the highest efficiency of the entire system.

A single information service on a state scale requires a great number of *information machines* installed in various towns specialising in various fields of science and technology, linked up by information transmission lines into a

single *information system* to which subscribers using information processed by the machines can be connected as need arises.

Of vital importance is the development of information machines which will gradually accumulate in their machine memory the contents of books, magazines, patents and other information material of great value—the result of the creative activity of humanity. Naturally the process of developing and introducing information machines will follow the path of creating machines specialised in various fields of knowledge: chemistry, physics, agriculture, metallurgy, medicine, automation, radio and electronics, etc. The necessity for intercommunication and contacts between specialists in various fields of science will spur the rapid development of a single machine information language, which should be tailored for different levels of the subscribers' knowledge. This subdivision of information will adopt it for specialists in narrow fields of science far apart as well as for those in related fields of science. The solution of the problem of information traffic between machines and subscribers is closely connected with the solution of another problem—the automation of telephone and telegraph communication on a country-wide scale. We already have automatic electronic machines punching information on cards and sending it from subscribers at high speed over the telegraph and telephone lines. Subscribers are linked up with the information system with the help of conventional automatic telephone stations.

In a single system contact between information machines can be maintained through a radio relay or conventional radio communication (with the help of transmitting-receiving radio stations).

Computing and commutating units receiving and transmitting information via a great number of channels, in each of which signals shift in series by bit form, are the main units of the information system proper.

Buffer memory units coupling the information machine and separate channels may employ *sequential-parallel* shifting of information.

Information is received by one of the memory elements situated on the lines sequentially, cycle-by-cycle and is

read out into communication lines from other memory elements. In the intervals between these cycles information from the machine can be recorded *in parallel* in any row of the memory elements or read out *in parallel* from the given row of elements. In this way a link is maintained between one machine of parallel operation and many lines with the sequential shift of information.

Specialised information machines are developed and used in trade and supply, in industry, in the army, in transport, in meteorology, etc.

*Supply service* information systems have machines at each wholesale trade centre connected with retail stores and with production. The flow of information in them on the country-wide scale is enormous. The system links up various points with communication lines totalling more than 50,000 km.

*Finance* information systems link up banks, their branches, savings-banks and machine computing stations. Reading machines automatically reading figures and letters directly from cheque papers find ever greater use as input units.

*The central systematic administration* is an information system consisting of a wide network of computing stations receiving information from scores of thousands of establishments, building jobs and processing it for further use in the planning of the country's economy, taking into account all data stored in the machine in the previous years. *Machine* digital information accumulated in the information systems throughout the country gradually will tend to increase the flow of speech information (over the telephone and telegraph). In this connection the network of commutation installations and communication channels is rearranged to ensure a continuous and reliable service of the information systems.

# Machine Processing of Information

## Machine Scientific and Technical Information

Modern practice requires the solution of very complicated scientific and technical problems in the shortest time possible with due account being taken of the results of all the previous research data contained in books and journals.

The better the country's information bibliographical service is organised, the more fully its potential riches stored in its libraries are used, the higher is the cultural and technical level of the land.

The higher competence and skill of specialists, together with the increasing number of scientific and technical workers result in an increase of technical research developments. Millions of scientists and engineers continue to enrich library collections and each of them can assimilate in his lifetime only a mere fraction of that information. This gap is widening with catastrophic rapidity. Humanity is faced with a problem essential for the development of our civilisation: the problem of assimilating the vast knowledge accumulated by humanity, of developing a system of information which will make it possible to obtain rapidly the required extensive information in any field.

The times of encyclopaedists such as Lomonosov, Euler, and Leibnitz have passed never to return. The rapid development of science and technology leads to the differentiation of various branches of knowledge, and specialists are finding it ever more difficult to keep track of all the new works that appear in their narrow fields, not to mention other branches of sciences.

The aphorism that the knowledge of scientists is widening while their field of knowledge is narrowing is very apt today. It becomes quite difficult for broad groups of special-

ists to fathom certain scientific papers in narrow fields of science. The terminology of each branch of knowledge today lies practically beyond the reach of a non-specialist.

It has been said that it is far easier to invent something anew than to prove that it hasn't been invented before.

A curious incident happened a few years ago. In the course of investigations conducted by the U.S. Congress it was established that the development of a certain special device required five years of continuous work and $200,000. Later it was found that the device had been developed in the Soviet Union long before the work in this field started in the U.S.A. The results of the work were published in a Soviet journal but the article was never translated into English.

Very characteristic are the figures pertaining to the search of information in the Patent Bureau cited by American journals.

By 1955 there were 2,700,000 patents granted in the U.S.A. and twice that figure throughout the world. More than 60% of the time required by experts to establish that an invention is original is spent in searching the Patent Bureau.

To find a patent in the U.S. Patent Bureau, one has to look through a collection containing anything from 1 to 10 million patents. It takes an experienced worker 4 to 6 hours to look through 350 patents.

It has been established that chemistry workers do experimental work only 35% of their time while 50% of it is swallowed up by reading, searching for material, or writing reports.

Scientists spend considerable part of their time selecting literature to obtain exhaustive information on the subject. According to UNESCO data searching for material in U.S. libraries costs $300,000,000 annually. To solve this problem a Library Council was established in 1956 with $5,000,000 allotted for the purpose.

In the Soviet Union there are several million engineers and nearly 200,000 scientific workers. If each of them requires on an average one extensive bibliographical reference once a year the total will be from 3 to 6 million references per annum or 10,000 to 20,000 references a day. Assume that information for each reference is selected from an average of 1,000 pages of text; it will require 10 man-days to select

the material for just one reference on the assumption that one bibliographer looks through 100 pages of text a day, while an effort of 100,000-200,000 skilled bibliographers will be required to carry out all the orders to examine the material. The salary of these workers will amount to several hundred million rubles a year. This task can be successfully tackled by information machines.

At present libraries using various systems of classification are of help for some of the specialists.

Library classification offers but a very brief description of the content of a book, i.e., it only hints to what branch of science the book belongs.

Classification of this kind requires a list of subject fields. Usually this list of fields is systematised by including particular sections in more general ones.

For instance, in the old decimal system of library classification the first number denotes one of these sections:

0—general;
1—philosophy;
2—religion, theology;
3—social sciences;
4—philology, linguistics, languages;
5—mathematics, natural sciences;
6—applied sciences, medicine, technology;
7—art, architecture, photography, music, entertainment, sports;
8—literature;
9—geography, history, biographies.

In the universal decimal classification section "thermochemistry", for instance, is included in the more general section of "physical chemistry", which in its turn is included in the section "general and theoretical chemistry", which is in "chemistry", which is included in the most general section of "mathematics, natural sciences".

We get the following pattern:

Mathematics. Natural sciences. Chemistry. General and theoretical chemistry. Physical chemistry. Thermochemistry.

The system in which particular sections are included in the more general one is evidently characteristic of a decimal system of classification. Figures from 0 to 9 serve to designate subjects of this system. Moreover, information is con-

veyed by the arrangement of the figures which denotes the relation of the particular section to the general.

The first figure denotes the largest division of the subject group (there are 10 altogether). The second figure denotes further division into subsections. Thus in our example with thermochemistry the section "mathematics, natural sciences" is included in the first division and has an index 5. The section "chemistry", which is one of the ten subsections of this section has an index 54. The figure 5 denotes the general section which includes the given subsection with a more complex index 54. Thus the consequent narrowing down of the subject field adds to the number of figures in the index. For instance, index 541 denotes general and theoretical chemistry, index 541.1—physical chemistry, index 541.11—thermochemistry.

Thus index 541.11 contains information on all the consequent inclusions of the word "thermochemistry" into larger and more general sections.

Decimal classification indices are written down on the books and serve as a brief description of the book content referring it to this or that field subject.

Classification of this kind is adopted in the State Lenin Library, where 26 letters of the alphabet are used as the first symbols of an index.

For example:

C—physico-mathematical sciences;
C 6—astronomy;
C 65—the Sun and its system;
C 655—small bodies of the Sun's system;
C 65.53—meteorites and boloids;
C 65.536—meteorite streams;
C 655.369—separate meteorite and meteor streams.

The same classification of material is characteristic of other systems. Thus an encyclopaedia of technical measurements published in the 'thirties was based practically on the same system of classification as the one used at the Lenin library.

The first sign of the index was one of the three letters selected by the mnemonic features; M—methods of measurements, I—instruments and apparatus, A—appliances and tool-building materials.

Example:
M—methods of measurements;
M 1—mechanical values;
M 2—weight, volume, the number of solid, liquid and gaseous bodies;
M 123—volumetric registration of the amount of liquid and gaseous bodies;
M 1232—registration of liquids by motor type counters.

Thus all the library languages we have discussed are based on the classification of subject fields.

The index which is an element of this language denotes that the paper or the book refers to one and sometimes to several subjects.

Moreover, it contains information on the larger sections in which this particular subject is included.

The data about each book is recorded on special cards. These cards are grouped under alphabetic, index and other headings. Their number is enormous. In the Lenin library alone there are 25 million cards in all the catalogues with about a million cards being added each year.

Mechanisation of the information retrieval process calls for more efficient classification. Different scientists approach this problem in a different way. Some suggest taking as the basis for the information characteristic a set of terms logically non-coordinative but required to denote the book or paper to be coded (a classification system with the help of determinants). Characteristic features denoting the content of a book or a paper and their numbers are recorded in the cards. To find the required material, the cards are selected by their respective specific features and a definite code figure selected from the figures with common features will give us the code of the material we are looking for.

The so-called "facet" classification is also well known. According to this classification, terms are distributed by groups or categories. For instance, in building, one facet is the subdivision by building material: wood, stone, concrete, etc.; another facet is the subdivision by production processes: earth moving, masonry, painting, etc.; a third facet can be the nature of structures and buildings.

However, these systems of classification have a number of shortcomings. Thus classification with the help of deter-

minants can be effective only for a very narrow field of science and technology, but with a greater amount of printed matter the number of determinants increases to such an extent that classification of this kind becomes extremely difficult.

Decimal classification is so immobile that with the development of various branches of science and technology it has become rather difficult to rearrange it.

At present the 18 classification systems existing at the State Lenin Library make the search for required literature very difficult. A special department has been set up which deals with the reclassification of literature.

The library of Moscow State University began reclassification way back in 1949 and it has not been completed yet.

If we take that one bibliographer handles 20 library cards per day or 5,500 cards in one year, it will take 180 man-years to process one million publications.

It is difficult to work out a more or less satisfactory classification system even for a short period of time; it is still more difficult to fill out numerous bibliographical cards for the already existing or new publications. Each reviewer is rather subjective in his approach and evaluation of the card. Take, for instance, a book which deals with a boiler plant at a chemical mill. When filling in the card a chemistry worker will be interested in chemical reactions, acids, etc., a physicist in the boiler gas pressure, a metallurgist in the behaviour of the boiler metal under overstress, in thermal proofing and corrosion, etc.; a builder will note the design and structural behaviour of the supports, the structure of the boiler plant foundation; a powerman will look at power transmission from the source to the boiler. Thus one and the same work can be referred to various sections of the classification system. If library cards are filled in by a worker of only one speciality this will result in the loss of information for specialists in the adjacent branches.

Considering the enormous amount of stored publications reclassification is a titanic task commensurate with a general census of the world's population, but requiring a far more qualified personnel to cope with it.

Library classification is closely linked up with the classification of sciences. It should reflect in brief the most

important problems dealt with in books and articles. Classification is ageing fast with the rapid development of science and technology. Thus, for instance, the last 10 to 15 years saw the appearance of entirely new branches of physics, chemistry, and biology which naturally could not be foreseen in the general classification system. It becomes more and more difficult to distribute library material by indices. And it is impossible to develop such a library classification which would envisage the development of science even only for the immediate future. The possible number of elementary sections of the ramified system of classification is truly astronomical—it is more than $10^{100}$.

The usual methods for the indexing and classification of the information accumulating has become an obstacle for the development of science and technology. At present many scientists in various branches of science and technology are hard at work developing new principles of scientific classification and coding of literature. Special information centres and bibliographical departments are set up, and review journals and reference books are published in many countries to help scientists in their search for required literature.

The centre of scientific information in the Soviet Union is the All-Union Institute of Scientific and Technical Information which employs over 2,000 staff specialists and nearly 20,000 part-time translators who process literature arriving from all over the world. More than 10,000 scientific workers and engineers compile reviews. Chemical Abstracts alone reviews more than 100,000 articles annually. In 1960 the Abstract contained nearly 700,000 publications based on 11,000 foreign and 3,000 Soviet scientific journals, collections and 90,000 patents from 90 countries. Nevertheless, the problem of obtaining required information remains one of the most difficult and most urgent problems of modern science and technology. The only way out of this situation is to develop new technical means ensuring automatic and efficient examination of the printed matter.

However, machine searching of information requires a suitable technology for the preliminary processing of information.

Information is sought by given attributes either manually

or with the help of machines. Libraries use various classification systems of the hierarchical type which provide but a very brief description of the content of a book or some other paper.

A descriptor system in which information is characterised by the combination of key words and individual terms called descriptors (from several hundreds to several thousands for each branch of science) has been developed to mechanise the process of information searching. Descriptors are holes made along the edges of a punched card in the middle of which there is a photograph of a paper. The required paper is sought with the help of needles passed through the holes of the given descriptors. The cards required are mechanically separated from the rest of the cards (1,000-5,000 cards). Mechanical searching makes it possible to seek information recorded on *minicards*, one part of which carries nearly 2,700 descriptors and the rest (approximately 2/3) contains microfilm with the text of the information sought. Magnetic cards, i.e., cards covered with magnetic material are also used as the carriers of information and descriptors. Each of them contains up to 5,000 bits. Nearly 5,400 such cards can be examined in one minute.

To speed up the searching process a by-descriptory system of classification of information is used. In this case, in manual search the number of cards is equal to the number of descriptors. A definite hole in the card corresponds to each document. When the material is selected with a given set of descriptors, their corresponding cards are retrieved from storage and are examined in a stack. The through holes indicate the numbers of documents, of which all the given descriptors fully coincide. This system of visual searching is quite efficient for several thousand documents (up to 10,000) and for several hundred descriptors.

The descriptor cards are 250×250 mm in size with 100×100=10,000 holes punched in them. There are nearly 100 cards in a pack.

A system containing 3,000 descriptors arranged on films (equipment cost—\$250,000) is also known. The system containing approximately 1,000,000 minicards of 2,700 descriptors each costs from \$2,500,000 to 3,500,000. Each minicard is a length of film 1.5-3.2 cm containing 12 pages

of text. A 240-descriptor selector sorting out 3,000 cards per min costs nearly $50,000. When magnetic tapes and discs are used, definite space is set aside for by-descriptor recording of document numbers. The cards are compared in the computer unit.

A more complicated system of information searching based on the use of special information language is now being developed which permits a fuller description of information.

## Problems of Machine Language

The same idea can be expressed by various words or sentences. This fact does not prevent people from understanding each other and from sharing experiences. However, in certain fields of science an exact unique wording of ideas is compulsory and the number of such fields is steadily growing.

Mathematics, in which whenever possible the language of words is replaced by the language of formulas and curves, is a graphic illustration of a science which demands exact wording; in chemistry much of the data on the chemical composition of a substance is expressed by set structural formulas rather than by words.

The exchange of experience between scientists would have been almost impossible without mathematical formulas, equations, chemical formulas, and diagrams, since the more complex the idea is, the wordier its definition becomes and this will not be unique.

For example, the rules demand that authors use a specific wording of the subject of their inventions in drawing up their claims. Otherwise it would be extremely difficult to determine the novelty of an invention and its significance for the country's economy. When the subject of an invention is worded briefly and specifically, the expert in most of the cases can confine himself to studying the subject of the invention without reading the whole text.

It has already been mentioned that in stocking the machine up with information the method of specific recording of the brief content of each work will be of especial value, since the reviewing of the material by specialists in narrow fields

of science leads to loss of information for scientists in the adjacent fields.

Machine information searching and its logical processing demand that the idea should be expressed uniquely so that the information material contained in the questions match the material stored in the machine in words and in the structure of the sentences.

True, assume that the information material arrives at the machine without changes, i.e., the sentences are recorded in the machine in the grammatical form of the initial text. Since the interrogation fed to the machine can be written down in some other grammatical form the machine has to convert the questions and change the places of the words in the interrogation.

Each time the interrogation is converted it is collated with the information contained in the machine. Thus the interrogation should be collated with the information as many times as there were conversions. The required material will be read out only when one of the forms of the converted interrogation matches the stored information.

Recording of information according to this principle would have naturally led to a considerable loss of time and would have been far from reliable, since an interrogation can be converted into such a form that the read-out information would not correspond to the initial question. Hence an auxiliary machine has to be introduced to process grammatically the texts of the recorded information and of interrogations.

The task is somewhat similar to that of machine translation from one language into another. In both cases the text has to be processed according to definite rules from the point of view of grammar. In word-for-word machine translation the text should be reworded in accordance with the rules of the language into which the machine is translating.

When forming standard sentences, words should be converted into indices (a certain code) and a specific connection of the indices in a sentence (in a group of indices) established.

Standardisation of sentences for the purpose of recording them in the machine facilitates and simplifies the task of translation from one language into another while the development of the theory and technology of the translating

machines will help to solve the task of bringing the content of information and interrogations to a single system.

Whenever possible a special unique system of recording scientific information should be created.

Measurement theory in physics makes it possible to express various physical values with the help of a few basic values. For example, if to characterise the phenomena dealt with in mechanics we take length $L$, mass $M$ and time $T$ as the basic values, then all the other mechanical values will be expressed as follows: force—$L^2MT^{-2}$, velocity—$LT^{-2}$, density—$ML^{-3}$, power—$L^2MT^{-3}$; in addition permittivity $\varepsilon$ or permeability $\mu$ are included to express electromagnetic phenomena.

Quantity of electricity is expressed as follows: $L^{3/2}M^{1/2}T^{-1}\ \varepsilon^{1/2}$, impedance—$L^{-1}\ T\varepsilon^{-1}$, etc.

Thus instead of writing down "electromotive force" we can use the formula $L^{1/2}M^{1/2}T^{-1}\ \varepsilon^{-1/2}$. If the text of the information contains such words as "electromotive force", "potential", "voltage", "tension", they all can be expressed by this formula.

The theory of similarity and analogy of physical phenomena can be used with great advantage for generalising information.

A formula comprised of physical values which also have numerical values can by analogy be extended, and an attempt can be made to compile for the machine formulas of the sentence consisting of notions (words) which have no numerical values. This will make it possible to perform with the help of machines all the necessary changes with formulas of the sentences similar to those performed with the ordinary mathematical formulas.

Symbolic methods of recording can be developed most fully by mathematical (or symbolic) logic. Links and functions in it are determined by special operative symbols. Many of them can be expressed by usual words and phrases of the conventional language. For instance: *yes*, *no*, *from*, *exists*, *thing*, *same*, *different*, *there is*, etc. However, a separate word of the language can render in our speech a whole number of meanings depending on the context, but in symbolic logic each word has one and only one meaning and is designated by a definite symbol. In the machine each symbol is expressed by a number. All the symbols are numbered.

The symbolic logic which has appeared as a result of application of mathematical symbols to logic can deal with statements, classes, relations, and properties. In contrast to mathematics which treats quantitative relations and deals with numbers, figures, arrangements and cofigurations, symbolic logic deals with non-numerical relations.

The representation of complex notions as the product of a number of simpler notions can serve as an example of such a system. For instance, the word **thermometer** represents a complex notion consisting of the product of three semantic multipliers: temperature control instrument. This system has been developed by the scientists W. Perry and A. Kent.

Let us deal in detail with the way the semantic code is formed. We shall take the term **telephone** as an example

The first step in constructing the code is to analyse the notion, i.e., to form its definition. Analysing the word **telephone** we arrive at the following conclusion: a telephone is an apparatus for the transmission of information with the help of electricity.

The definition of the word telephone includes four particular definitions: apparatus, transmission, information and electricity. These particular definitions from which the code is formed are called semantic factors. They are the building materials for the word code.

Semantic factors are arranged in a special table in which each of them has its own code designation. For example:

| | |
|---|---|
| apparatus is designated by code | M—ch |
| transmission | T—Rn |
| information | D—cM |
| electricity | L—cT |

The table is arranged on the basis of classification of notions. Classification of this kind makes it possible in reviewing to construct a code for new notions.

Usually, when coding the terms, the semantic code is fully selected from a special dictionary and not composed arbitrarily. Such a distionary for the translation from the conventional language into code language is compiled beforehand. It is based on the alphabetic principle. There is also a reverse dictionary also based on the alphabetic

principle, which makes it possible to change from the code back to conventional language again.

After the term which is being coded is expressed with the help of the code for the semantic factors, the gaps in the codes are filled with the signs of the relations. They determine the terms not only by their relation to the class of notions expressed with the help of semantic factors but also by the relation of the coded term to them.

Let us examine the relation of the coded word **telephone** to the semantic factors M—ch, T—Rn, D—cM, L—cT serving as its description.

Telephone is included in a class of apparatus designated by the semantic factor M—ch. The analytical introduction to the class is designated by the letter A which is included in the semantic factor M—ch; we get MAch.

The telephone is used for transmission. Therefore, the letter U which means that the coded word is capable of the action determined by the given semantic factor is added to the semantic factor T—Rn; we get TURn.

The letter W means that the coded notion acts upon what is designated by the semantic factor to which this letter is added, in this case to factor D—cM (information); we get DWcM meaning that the telephone transmits information.

Finally, a telephone operates with the help of electricity. The letter Q added to the semantic factor L—cT explains this fact and we get LQcT.

As a result we have DWcM LQcT MAch TURn.

This method of coding the notions makes it possible to search for the information by separate combinations of notions. At the same time this method makes it possible to describe more fully the information contained in the papers, which become available for machine searching with the help of a special code.

The document processing by this method is divided into several subsequent stages.

At the first stage the usual review is drawn up, as for instance in such abstracts as "Chemistry", "Mathematics", or "Machine-building".

At the second stage the content of the review is specially analysed to find out the basic elements of the meanings of the terms and to establish relations between them with the

help of a special diagram. These relations include: the initial material of the reaction, its result, character, catalisers, etc.

In the third stage these relations are expressed by three-letter indices which are taken from a special table while the terms to which they relate are coded with the help of the semantic code described above.

Here is an example from metallurgy. Assume that the content of a work is determined from the following title: Mechanical treatment of beryllium by rolling, forging and similar processes.

The analysis of the phrase gives a set of terms and their interrelations. Here the composition has the following elements (terms): **beryllium, treatment, rolling, forging.**

The interrelations of these terms will be as follows: beryllium is a material which is subjected to a process; treatment, rolling and forging are the processes.

As a result we have the following pattern:

| Relations | Terms |
|---|---|
| Material processed . . . . . . . | Beryllium |
| Process . . . . . . . . . . . . . | Treatment |
| Process . . . . . . . . . . . . . | Rolling |
| Process . . . . . . . . . . . . . | Forging |

The next stage is coding. The relations are coded with the help of three-letter indices taken from the table, and the terms by the semantic code.

Various relations exist in various fields of knowledge, and, therefore, various letter designations. For example, for chemistry we may have the following relations:

KOV—given property;
KEJ—material to be processed;
KAJ—initial material;
KUJ—component;
KWJ—product;
KQJ—with the help;
KAD—machine or device;
KAG—subgroup;
KAL—processed.

Substitute relation indices in our example; KEJ—beryllium, KAM—processing, KAM—rolling, KAM—forging.

For the term **beryllium** we select in the dictionary code MATL4—BQE, for **processing**—CUNG. MWTL. PASS001, for **rolling**—MQCL. MWTL. PASS001, for **forging**—CUNS. 030.

Thus the sentence in our example will have the following form:

KEJ—MATL 4—BQE;
KAM—CUNG. MWTL. PASS001;
KAM—MQCL. MWTL. PASS001;
KAM—CUNS—030.

This system can be very convenient for mechanising the process of coding and decoding.

Telegraph-type reviews are quite useful at certain stages of the development of machine language. At present, work is underway to develop a machine language which will embrace the content of information more fully.

When machine-processing the material it is necessary to: 1) compare the elements of information (sentences) to determine its novelty; 2) to replace particular notions by more general ones to determine their more general properties.

Here is a very simple example of the usefulness of such generalisations for obtaining the required information from the machine.

Let us ask the machine: "What are the properties of the diagonals of a rhomb?" We are interested in all the properties of the diagonals. The machine contains the following definitions of the theorems: firstly, that the rhomb diagonals are mutually perpendicular and divide the rhomb angles in half; secondly, that the rhomb diagonals are its axes of symmetry. Therefore, on the basis of this record we shall obtain information that the rhomb diagonals are mutually perpendicular, divide its angles in half and are its axes of symmetry. But there will be no indication in our answer that the intersecting rhomb diagonals are divided in half since the machine does not contain a definition to this effect. This is explained by the fact that the property of the quadrangle whereby intersecting diagonals are divided in half is true not only for the rhomb but also for a broader class of the quadrangles—parallelograms.

The machine contains the definition of a theorem that the

intersecting diagonals of a parallelogram are divided in half, and since any rhomb (a particular notion) is a parallelogram (the general notion) then all the properties of a parallelogram refer to a rhomb as well. To obtain from the machine all the properties of the parallelogram diagonals (they refer to the rhomb diagonals as well) we must substitute for the particular notion **rhomb** in the question "What are the properties of the diagonals of a rhomb?" the more general notion **parallelogram**. Further, the notion **parallelogram** can be substituted by a still more general notion—**quadrangle**; then we shall obtain yet another property of the quadrangle diagonals, and hence, in particular, a property of the rhomb diagonals: that they join apexes which are not adjacent to one and the same side.

Thus by substituting in the question more general notions for particular ones we can gradually obtain new properties of the subject which we are interested in.

In this connection the Electromodelling Laboratory conducted research in recording scientific information in a unique form. Geometry was the first subject of the research. The rules of converting grammatically complex sentences into standard sentences (into qualitative notion formulas) were drawn up, as well as the rules for converting these standard sentences back into the initial grammatically complex sentences. To check these rules in practice, a dictionary of basic notions (in geometry) and a dictionary of equivalent word combinations were compiled on the basis of Gilbert's "Foundations of Geometry".

There are various methods of sentence standardisation. Thus, for instance, we may introduce into the machine the rules of by-formula analysis of separate words in a sentence as well as whole constructions (word combinations or semantic groups). In this case, the machine should retrieve according to a definite programme syntactical links between the words as well as semantic links. Connections between words, first of all should be established by the grammatical values of basic words which can be determined without the context and then by the morphological structure of the sentences and semantic links.

As a result two-word and more complicated word combinations are established. To avoid incorrect separation of

the word combinations a definite sequence of operation should be observed.

The principal words (subject and predicate) are singled out in a sentence, and boundaries between simple sentences in a more complex one determined and complex syntactical structures singled out. The analysis proceeds from word to two-word combinations and from them to more complex combinations, and only after that simple sentences are singled out.

Whatever the analysis methods the machine must contain a dictionary and the rules of analysis.

Machine dictionaries used in language translation usually contain basic words and grammatical tables.

The principle of analysis by semantic groups presupposes a combined word dictionary containing words in all their forms except those rarely met in scientific texts. Moreover there should be a structure vocabulary containing combinations of indices corresponding to all possible word combinations met with in the Russian language.

The text fed into the machine is first processed in the dictionary where each word acquires grammatic and semantic accompanying information in the form of indices. At the dictionary output sentences are substituted by combinations of indices which are fed to the automatic structure dictionary containing all possible combination (two-word) pairs. The sentence (combination of indices) is read out when the given combination of indices matches with those recorded in the dictionary.

Specific recording of information according to any of the methods being developed requires:

a) an automatic dictionary with a considerable amount of stored information;

b) a system of automatic dictionaries for recording grammatical information;

c) dictionaries for recording word combinations with a large amount of stored information;

d) a well-developed programme of logical functions;

e) a high-speed logical device for the rapid examination and processing of the vocabulary and grammar information.

Specific information can be recorded successfully only when a long-time large-capacity machine memory as well as

the associative and vocabulary address systems discussed above are used. An information and logical machine itself can serve as an "intermediate" machine for the text standardisation described at the beginning of the paragraph.

The recording of information in specific form will sharply increase the machine's speed of operation, make automatic reviewing and standardisation of the text performed by the information and logical machine more reliable and extend its possibilities.

By substitutions, the machine can reduce the given question to equivalent questions which are simpler in form and can be processed by the machine. It will be easy to check and find out if there are no contradictions between the incoming and the recorded information and, if there are, to establish where and in what.

When sentences are recorded according to formulas by substitution and conversion, it can be established with the help of a machine whether a statement fed into it is the corollary arrived at through the processing of the material stored up in the machine.

In this connection some very interesting results can be mentioned on the deduction of formulas with the help of small-capacity machines. The scientist Hao Van has developed a machine algorythm and programmes for the automatic deduction of more than 400 theorems from the "Foundations of Mathematics" by Russell and Whitehead. The electronic machine proved 200 theorems from the first 5 chapters in about 3 minutes. Another programme was drawn up by Hao Van as an instruction to form suggestions from the basic symbols in argumentation and to obtain non-trivial theorems. Approximately 1,000 theorems were found in an hour with the help of the machine. The machine has formed and checked 14,000 suggestions. However, this programme has an insufficient number of associated properties to distinguish trivial theorems from the valuable ones which are of interest. The next and very difficult task is to develop and introduce into the machine the criterion of nontriviality. When proving new theorems, all the previous ones should not be retained in the machine memory. Most of the intermediary calculations should not be stored up in the volatile memory. Only one line from each demon-

stration level in its branch form should be retained. Thus for example, one complete demonstration of one of the theorems contains nearly 16,000 lines, but a maximum of 13 lines is stored up at each demonstration step; all in all it takes $13 \times 72 = 936$ memory cells. (There can be 72 symbols in each line recorded in the memory cells.) The thing is that in this algorythm, axioms and definitions are not included in the process of demonstration and are regarded as theorems. However, this is not always possible and when more complicated cases are dealt with, reference has to be made to the already proven theorems, definitions and axioms and this in its turn calls for a more extensive memory.

The main difficulty for further work lies in finding the criterion of value and usefulness of the results to be selected from a host of definitions and theorems worked out by the machine. Hao Van points out, in particular, one such criterion: a *short formula obtained through long demonstrations* is evidence of a valuable result.

*Automation of book reviewing* (*first steps*). The systematic properties of scientific information may offer material for the finding of regularities, which in the future will help to mechanise the process of information indexing. Attempts are being made to use machines for automatic "*reviewing*" and abstracting. This is to be understood as the selection of a certain number of the most "weighty" and valuable sentences out of all the sentences in the text. The more often these words occur in the text the more importance they acquire and the more weight each of them attains. First of all the text is cleared of "noise", i.e., from words of a general nature—pronouns, prepositions, articles, etc., whose frequency of usage is of no importance, since they are not the objects of the search. Then the machine counts the number of repetitions of each word in the text. One word can be repeated 120 times, another one 112 times, a third 81 times, etc.

Words whose recurrence in the text is above a certain threshold established experimentally are singled out.

After that all the sentences without "noise"-words are once more run through the computer and their "statistical weight" is calculated according to the following formula:

weight is equal to the squared number of "weighty" words in the given sentence divided by the total number of words in the given sentence.

Here is an example. Assume that the given sentence consists of 12 words, of which 4 are "noise"-words. Without them there are 8 words in the sentence. If there are only three "weighty" words which occur fairly often, then the "weight" of the sentence will be $1^1/_8$ (three squared divided by 8). In a sentence containing the same number of words but with 4 "weighty" ones this "weight" will be 2. This formula is based on the well-known assumption that the plurality of the word meaning corresponding to its semantic weight is proportional to the square root of its recurrence. This formula insufficiently differentiates "weighty" words with different rates of recurrence since beyond a certain threshold they all play one and the same role in this formula. The use of a formula has been suggested which takes into account the relative recurrence rate of each word in the given text, i.e., the number of times it has been introduced into the text. Great possibilities open up for the selection and evaluation of words in the text with the help of automatic dictionaries which can read out for each word its essential *semantic* information. The semantics of all words in the text properly and logically processed, taking into account their rate of occurrence, permit the improving of the method of selection of "weighty" words in the works under review. The recurrence of one and the same semantic features is a reliable indication of the content, and it will be rather difficult to make a mistake in the evaluation of the subject of the given work and to reveal the "weight" of the sentences in it.

Such methods of machine retrieval of certain sentences from a lengthy text can be used until more effective methods of machine reviewing are developed by combining the possibilities of large-capacity information and logical machines with the development of linguistic semantics, logic and the theory of algorythms.

It must be emphasised that the reviewing process is one of the most complex processes of mental activity.

The machine method of the analysis and synthesis of scientific material will help to expand the range of problems

that can be solved with the help of new machines. In the future an encyclopaedic machine will undoubtedly be developed containing all the known, specifically formulated axioms, theorems, formulas, definitions and other data. New results and generalisations can be introduced into the machine after the machine checks them for novelty. No compilation will find its way into the machine. The machine-encyclopaedia will help to issue references which are quite original from the scientific point of view, will trace new analogies in various natural processes, in formulas, laws, etc.

By using logical patterns of investigation of material, a corollary from the prerequisites relating to two different branches of knowledge (for instance, a corollary for physical chemistry from the prerequisites for physics and chemistry) can be established.

The contents of review journals, handbooks, textbooks and patents will serve as the basic material for the first information machines.

## Processing Chemistry Literature

The sharp increase in the flow of scientific information is especially tangible in chemistry—the science in which the number of individual objects of research, i.e., the number of chemical compounds, has long passed the one million mark, while the number of concrete chemical reactions which have been described in scientific papers has reached many millions. In 1957 the Soviet Chemical Abstracts alone published 106,000 papers, and in 1958 it published 117,200.

Work with chemistry literature, which besides searching for information includes its analysis and comparison, is one of the most important aspects of mental activity taking up an ever greater part of the chemist's working time. The efficiency of his research work largely depends upon this. Nevertheless, at present, although they solve numerous problems, chemistry workers rely on their personal knowledge and on a far from sufficient examination of literature, since a thorough search for information and a thorough study and comparison of all the data pertaining to a problem will take up an enormous amount of time.

It is easy to realise the vast vistas which open up today in connection with the progress in technology. For now large high-speed information and logical machines with a large-capacity and rapid-access memory can be developed.

An information machine will provide a wide range of chemistry workers with information concerning chemical compounds and reactions, and later on dealing with the most varied physico-chemical systems.

For the information machine to perform these functions, the necessary information should be recorded in it in some artificial language and with its help the machine will carry out various retrieval and logical operations. Information, translated into machine language, after it is coded in binary code, is recorded in the long-time memory.

Thus the development of a large-capacity chemistry information machine requires beside the appropriate technical means the creation of a machine language to provide the machine memory with code information.

From the point of view of the development of a machine language for the basic information in chemistry—data concerning chemical compounds and chemical reactions—the fact that chemistry has long ago formed the language of the structural formulas of chemical compounds plays the decisive role. To make this language suitable for machine operations, the structural formula should be presented as a certain linear succession of symbols. The last decade saw many papers devoted to the development of various systems of linear encoding of the structural formulas of chemical compounds. However, in most cases the aim of these works was to develop the encoding systems adopted for their use by man (for instance by indices).

Analysis has shown that the codes which are to serve as machine language terms should answer special requirements, all the more so since the machine should perform various operations in retrieving and converting structural formulas.

On the basis of these requirements the Laboratory of Electric Modelling has developed a system of the canonical linear recording of the structural formulas of the chemical compounds adopted for various machine operations. At present there is a possibility of automating the process of the conversion of information of structural formulas of chem-

ical compounds into linear records using the machine for this purpose. This means that all the chemist has to do is to write the structural formula of a compound in its conventional form; after which it will be translated into machine language, recorded in the machine memory without the participation of the chemist, but with the help of technical personnel or even without man's participation (as automatic reading devices are being developed at present). After processing information the machine itself converts linear (one-dimensional) records into structural formulas (two-dimensional recording).

When speaking of loading the information machine memory with information dealing with chemistry, two aspects of the problem should be borne in mind: the recording in the machine memory of all information which has accumulated in the literature up to the moment the machine began to function, and the replenishing of the machine memory with current information.

The second task can be easily solved if the data for the machine is selected in parallel with the processing (reviewing) of all the printed data on chemistry at the Institute of Scientific and Technical Information for the review journal "Chemistry" and for its indexes.

The first task is more complicated, i.e., to introduce into the machine memory all the information on chemistry which has piled up in the course of almost two centuries.

One way to solve the task is to put a considerable number of scientists on the job. The machine itself will be used to translate information prepared by the chemists into machine language.

The second, more effective way of eliminating mistakes and subjectivity in the evaluation of information is the use of automatic reading devices for translating scientific and technical texts into machine language. Of great importance from this point of view is the work conducted at present in nomenclature translation, i.e., in the automatic translation into machine language of the arbitrary names of chemical compounds. The solution of this problem is all the more important because it becomes possible to automatically identify in any arbitrary text words denoting the names of chemical compounds.

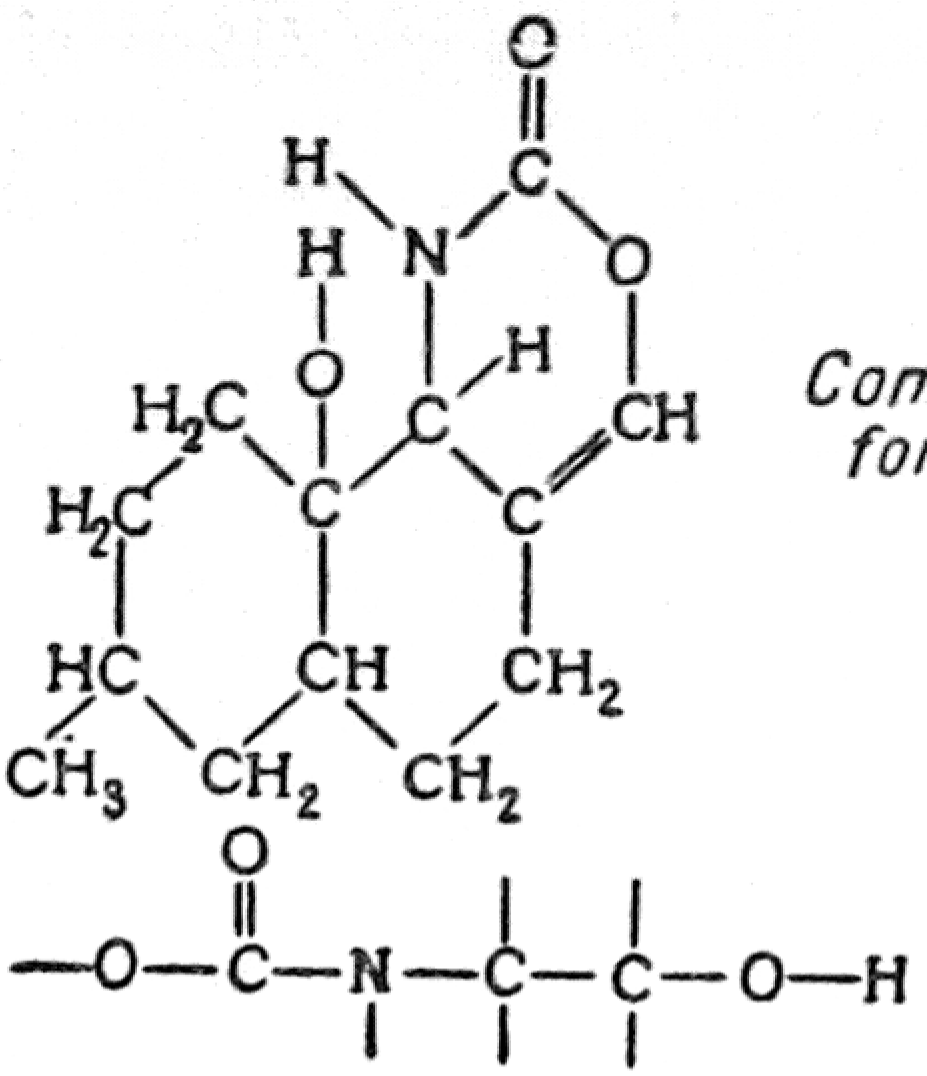



*Fig. 46.* Chemical structural formula and the sought for portion

Here is the structural formula of a compound: 4a-oxy-6 keto-$\Delta^8$-perihydro-7-oxy-5-azaphenantren and a formula of one of its portions (see Fig. 46).

By a portion of the structure we mean any arbitrary substructure. Here portions, the carriers of various physical, physiological and chemical properties, will be the objects of the search.

The portions of practical value are statistically subdivided into two subgroups: portions consisting of 3 to 4 atoms, called chemical functions, and large portions of about 15 to 20 atoms which are the carriers of various properties.

The automatic translation of arbitrary names of chemical compounds permits the interrogation of the machine about chemical compounds using any form of their description. At present the principles of the solution of this problem have been elaborated. A dictionary of chemical syllables, i.e., a dictionary of particles should be drawn up which make up the names of chemical compounds. This vocabulary which will be stored up in the chemical information machine and used as a high-speed automatic dictionary should also include the empirical names of chemical compounds.

Using the machine language as an intermediary language the chemical information machine will be able to convert

any form of description of the composition of a chemical compound into any other form.

A translation of this kind from any "dialect" of the chemical language into any other "dialect" of the same language is needed in drawing up various chemical indices. By combining the automatic search for the names of compounds from printed matter (and of their bibliographical coordinates) with automatic translation of arbitrary names of compounds into names made up according to a certain given set of rules, the chemical information machine will fully automate the process of compiling such chemical indices, as for example, the compound formula index. Moreover, the machine will be capable of drawing up rapidly specialised indices systematising the material by any given properties.

In principle, concrete chemical reactions are recorded without much difficulty with the help of the linear code of the compounds taking part in them and by adding a special sign corresponding to the sign of the arrow in the conventionally written reaction.

Making use of the address system of the long-time memory, it is convenient in recording chemical reaction formulas to replace the codes of the compounds taking part in the reaction by the memory cell addresses which contain codes of these compounds.

In turn, not only the accompanying information on the properties of the given compound should be recorded in the memory cells containing the codes of the individual chemical compounds, but also the addresses of the memory cells containing all the reactions in which it takes part and in which it is produced.

This system of cross references realised in the chemical machine memory on the basis of the address system not only permits the recording of the most important compounds in the most rational way but at the same time makes it possible by starting from a given compound to find at once all the compounds out of which it is obtained, or all the compounds which can be formed from it. Compounds thus obtained can in turn either lead to their possible predecessors or to the products of conversion, and a synthetic chain can be easily traced either to more simple or more complex compounds.

Of great importance is the recording of the types of chemical reactions as the so-called "chemical analogy" or "chemical thinking" is expressed most vividly in the notion of type of reaction, taking as a basis those occurring in organic chemistry. Each type of reaction is characterised as a certain "standard equation", given with the help of one or several initial or final portions of the structure. These portions or structural elements of molecules, undergoing changes in the process of these reactions are recorded in the machine language in the form of linear codes.

Besides information about chemical compounds and their properties and reactions, other information which is graphically expressed, as for instance, compound spectra, diagrams of states, etc., can be introduced into the machine. Work is under way at present to enlarge the chemical information language and to adjust it for the recording of information about the mechanism of chemical reactions and about the technical means for conducting them, as well as about the properties and behaviour of various physico-chemical systems. The aim of this work is to embrace gradually the multitude of information dealt with in various branches of chemical science.

Let us, for example, examine the diagram of a machine for processing and retrieving chemical information (Fig. 47). The information machine long-time memory with the capacity of a hundred million bits contains information about scores of hundred thousands of chemical compounds and about millions of chemical reactions. One recorded structural chemical formula is the unit of information, called the word. Words are formed from letters (the symbols of separate atoms), the links between them and other signs. Recorded formulas of chemical reactions comprised of words, the structural formulas of the compounds taking part in the reactions and data about the technical means of their implementation, etc., are the information. Input units include automatic devices for translating chemical information fed into the machine into machine language. The information machine output units produce the reverse translation into the language of structural formulas and special terms convenient for chemists. The final results of the machine operation can be reproduced with the help of charactrons coupled to the

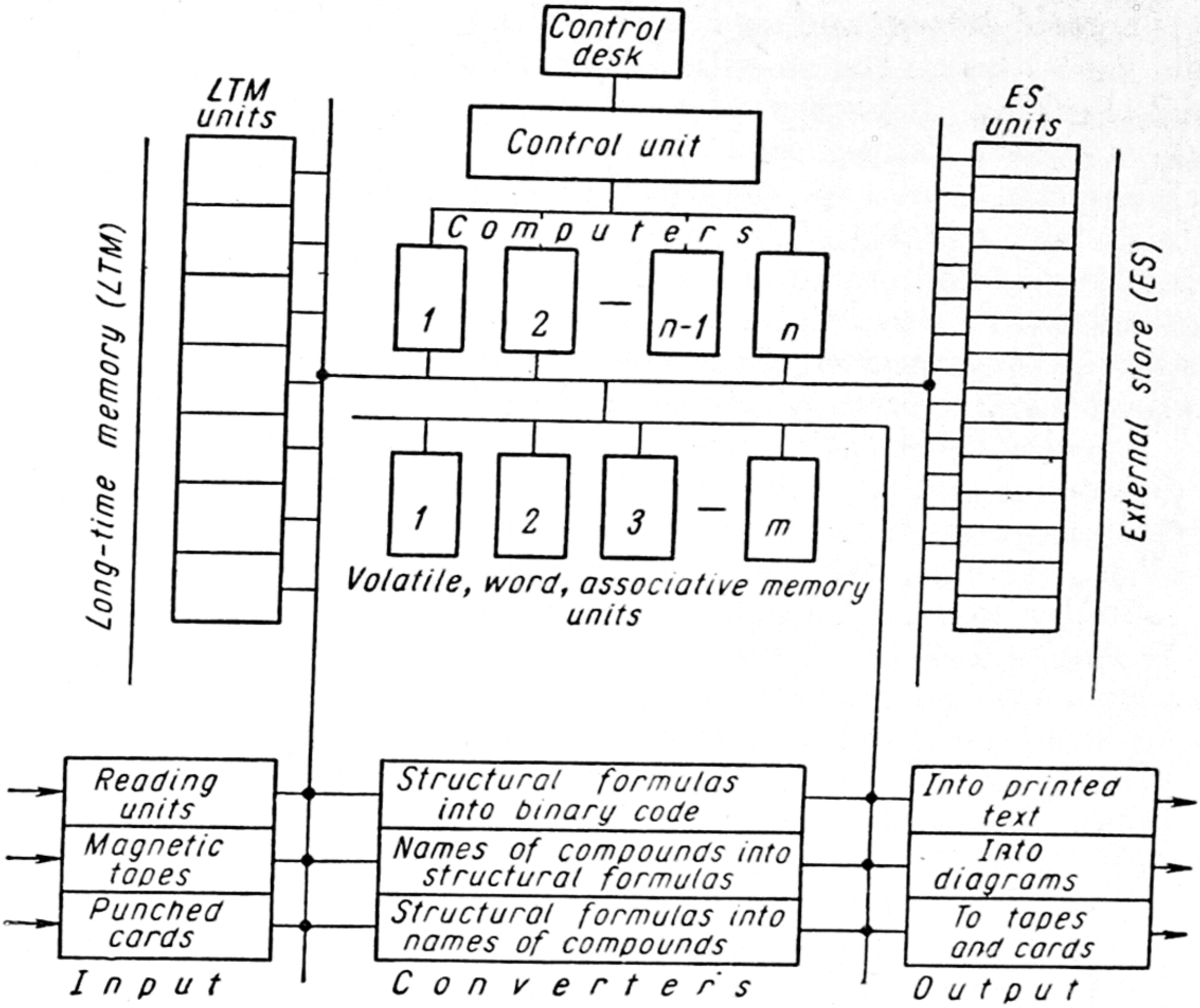



*Fig. 47.* Block diagram of chemical information-logical machine

serographical printer capable of 10,000 symbols per second (nearly 5,000 lines per minute) with 120 symbols in a single line.

**Input devices.** Keyboards, image converters and diagram input devices can be employed as input units. Moreover, magnetic tape, discs and punched tape can also be used.

**The translating device.** The unit converts chemical information fed into the machine into linear code. It comprises: a unit for converting information into structural formulas, a unit for converting structural formulas into linear code, an automatic dictionary and a volatile memory. The translating device is a self-contained unit used for solving problems and for adding fresh information to the machine long-time memory.

The unit converting the names of compounds into structural formulas in solving straight forward chemical information problems should possess the following characteristics: the long-time memory with its dictionary and conversion programme should have the capacity of about 60 million bits, while the volatile memory has 2,000 addresses.

The converter should in the main perform logical operations, substitutions and certain elementary operations like addition. The unit selects words from the automatic dictionary. The words are not specified, i.e., their boundaries are indefinite, since this can be done only by programming or by introducing changes in the machine circuit.

Structural formulas can be converted into linear code either with the help of a special unit as is shown in Fig. 47, or by using for this purpose the machine computer which seems expedient for the solution of these problems.

Further on, structural formulas can be converted into linear code in a separate converter so as not to overload the machine's computer.

**Computer.** The computer will contain several units of the volatile memory, units performing logical operations and operations of comparison, counters and matrix systems for parallel selection of information according to many attributes.

The machine circuit should be designed to handle simultaneously several problems, since at different stages of the problem solving, different machine units carry different loads.

**Control unit.** The problems of retrieval are monotype problems and hence programmes can be stored in the long-time memory.

The machine long-time memory should contain units of the large-capacity memory in which over 1,000 million bits of information on chemical compounds and reactions can be recorded.

Besides numerical retrieval of information the machine must carry out associative and dictionary retrieval.

The machine long-time memory may for example be arranged as follows.

Compounds are recorded in the units which have definite combinations of accompanying attributes as their addresses.

Inside the unit compounds have their own addresses (they are repeated in each unit, because the number of compounds in each unit is approximately the same).

The unit addresses may, for example, be the empirical formula of a compound and various types of the so-called empirico-structural attributes (i.e., blocks of structures of a definite standard form).

The information is retrieved as follows.

A group of memory units possessing the required address attributes is selected by the address attributes given in the portion. Since there are several address attributes, the addresses are selected in stages, the circle of the addresses required for further performance gradually being narrowed down.

Preliminary address attributes can be arranged more accurately only when statistical calculation of the distribution of compounds by these attributes has been carried out.

After the addresses of the units participating in the search are determined, compounds are examined in comparison with the attributes indicated in the accompanying information.

Only those comparatively few compounds which were not discarded in the preceding stages of the search will participate in the processing by the main algorythm of the search. With an appropriate selection of properties only a tenth of the whole multitude of compounds containing the given portion may be processed, thus considerably speeding up the processes of searching.

Since the speed of information retrieval from the memory is 30,000 compounds (information on the attributes) per second, and parallel matrix systems are capable of performing comparison and logical operations also at high speed (approximately the same), it becomes possible to ensure a high speed selection of the compounds by quality attributes—about one thousand compounds per second, i.e., 600,000 compounds can be examined and selected in 10 minutes.

The machine output unit should be capable of:

typing the compound ordinal (in some sort of index);

typing the name of a compound in some defined form (in the nomenclature system);

graphic representation of the structural formula of the found compound;

typing of the accompanying, for instance bibliographical, information in letter code;

giving "yes" or "no" answers.

The machine output unit should be provided with devices for converting the machine linear code into the names of compounds and into diagrams, and for translating the machine linear code into ordinary text. The input and output devices will compile formulas and systematic indexes of the compounds.

Recorded in the machine memory will be compounds encoded by a simple linear code. The recording of one structural formula represents a unit of information, called a word. The average word length is approximately 45 "letters" (the maximum is several times greater).

Each structural formula recorded in the memory is supplied with additional information (on various attributes and special data concerning the compound) in letter or digital code.

The encoded question introduced into the machine contains either information about the compound sought in the form of the encoded structure (an individual compound is sought), or information about the sought class of compounds in the form of an encoded portion of the structure or a set of attributes (various specific features of compounds) interconnected by definite kinds of logical relations and encoded in accordance with the code of the additional information in the memory.

The average word length of the portion is approximately 15 letters (the maximum is several times greater).

The word length of the accompanying information for a compound or for a portion is about twice greater than the length of the main word (if a word contains 45 "letters", the accompanying information will have 90 "letters").

Thus information consisting on an average of 120-letter words will be required to record each compound in the machine memory. If the length of a "letter" is 10 bits then it will take 1,200 bits to record one compound.

Analysis shows that in order to increase sharply the by-portion access speed, the volume of the per-compound in-

formation word should be approximately doubled, i.e., the basic information percompound should contain on the average 45-letter words each.

Nearly 1,000 million bits will be required to record 600,000 compounds. It will take a highly skilled chemist 3,300 working hours to examine 600,000 compounds, i.e., nearly 18 months. The machine can do the job in an hour, examining 10,000 compounds per minute.

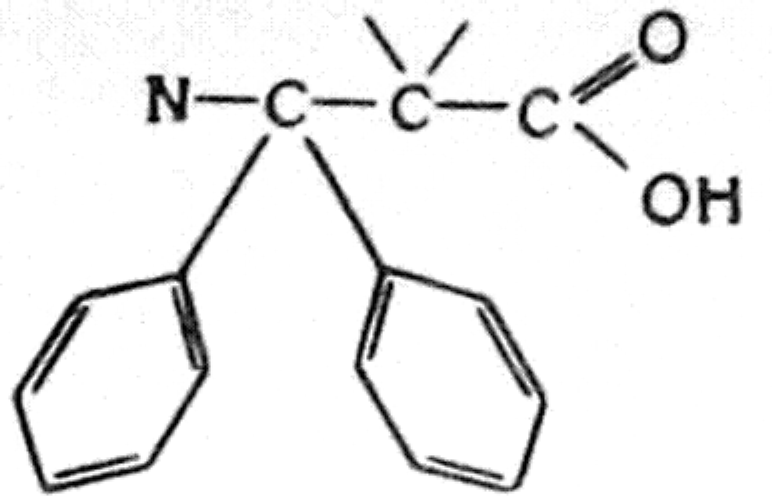
The access speed in the experiments conducted by U.S. scientists for a restricted range of problems (in the oil industry, in insecticides) was approximately 10,000 compounds per minute with by-unit recording of structures (the work of Oppler).

The simplest type of information problem which the machine can tackle is the read-out of all the information it stores (physical properties, references) about some given chemical compound. In solving such problems the machine functions as a simple one-dimensional index. But even in this case the access speed of the machine is not to be compared with the speed with which this problem is tackled by man. Instead of the hours needed by chemists to pore over the summary indexes of dozens of review journals, it will take the information machine supplied with an automatic dictionary described as above only a fraction of a second to perform this operation.

However, if all the compounds possessing definite specific structural features due to the presence or absence of these or those portions of structure have to be found, the operation cannot be carried out with the help of indexes because of the multi-dimensional character of the search.

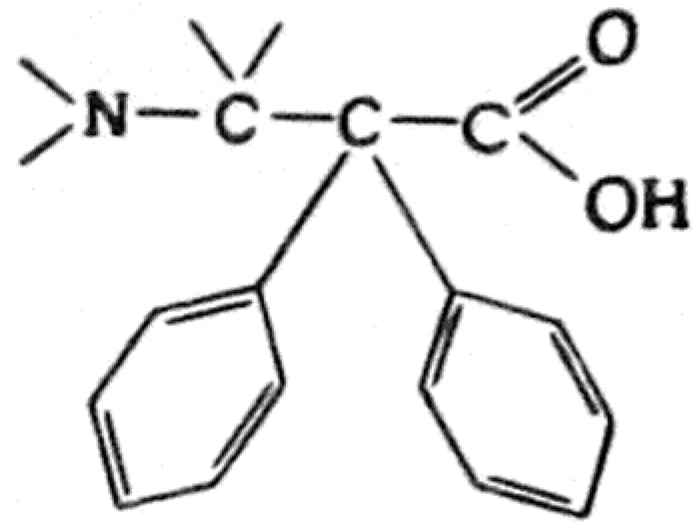
For example, if all the ß-amino acids containing two hemminal phenyl groups in a molecule, but free of haloids had to be found, or all the compounds which contain an aldehyde group bound up with the saturated seniglen carbon ring containing no less than two other substitutes, etc., the answer to these problems can be provided by the machine only. The solution of these problems from the machine point of view is tantamount to a search of all the compounds which contain definite kinds of structural portions.

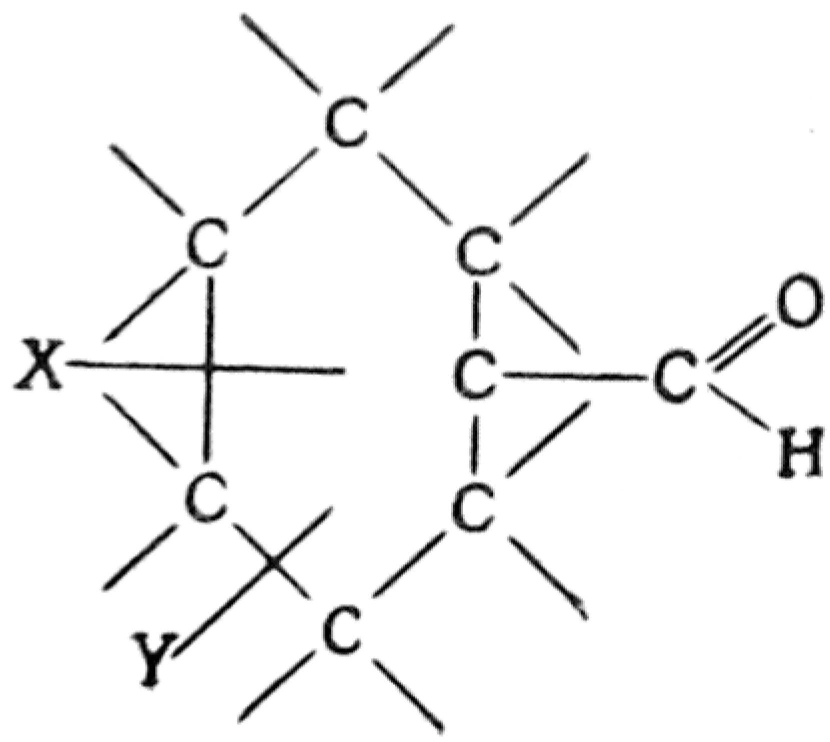
In particular, it is evident that the first example concerns the search for compounds containing one of the por-



I

or





II

*Fig. 48.* A problem of information searching

tions of type I, whereas the second example concerns a search involving a portion of the type II structure where X and Y are arbitrary atoms, different from H (see Fig. 48).

Another example of a multi-dimensional search, which can be realised in this first-stage chemical information and logical machine is the search for chemical compounds possessing a definite set of values of their physical constants, or for some other like attributes such as, for instance, the presence of particular structural elements in the compound molecule. Thus, if a substance with unknown structure is extracted from some living organism with a melting point close to 223° and with a specific rotation of +106° and if the preliminary functional and qualitative elementary analysis reveals the presence of, for instance, two carbonyl groups and one oxide group, as well as the presence of one ethylene bond and the absence of heteroatoms differing from oxygen, it will take the information machine a mere several minutes to establish that among all other compounds de-

scribed in the chemistry literature only 17-oxiprogesterone answers the above described set of properties.

To select groups of compounds by given attributes or by combinations of these attributes, the computer can perform logical operations with the accompanying information and simultaneously with all the attributes given in the question. While searching for the given combination, the machine examines compounds at the rate of 30,000 compounds per second.

The design of the machine computer provides for the simultaneous performance of all three types of search. While one part of the computer unit is engaged in the by-portion search (a more lengthy operation), other units seek out compounds by combinations of attributes and retrieve individual compounds at the rate of 30,000 compounds per second. The chemical information and logical machine is capable of many types of search in the fields of chemical reactions.

Somewhat more complicated information problems are the problems of finding the ways of synthesising a definite given compound starting from a certain permissible set of initial products and using the processes of chemical conversions described in the literature. From the viewpoint of these problems the entire factual material of preparatory chemistry, of synthetic organic chemistry in particular, can be represented as a vast diagram whose points denote various individual chemical compounds and arrows connecting them —the various processes of interaction taking place between these compounds described in chemical literature.

Assume that we are faced with the problem of finding ways of synthesising a definite compound from another compound or from a certain given assortment of possible initial compounds, and it is desirable that the synthesis chain has a minimum number of intermediary stages. This problem is connected with the analysis of a large number of possibilities and it becomes very complicated if the number of compounds is great, even when the speed of movement along the synthesis chain is high.

However, we can make use of the associative memory permitting the storing up of diagrams of the indicated type and the seeking of shortest routs between the two given points (or between a point and a host of points).

These routes are sought not by examining all possible combinations one after another, but rather in an "avalanche"-like way with all the possibilities examined simultaneously. As a result the machine will produce the shortest possible chain of compounds synthesised one from another; each chain link comprises one initial and one final compound.

When searching for ways of synthesising the given compound, the machine operates on the basis of the information concerning the chemical conversions recorded in its memory. The same problem can be solved on the basis of chemical analogies recorded in the machine memory in the form of standard equations of reactions plus accompanying information concerning their field of usage. In this case the machine will already be solving typical information and logic problem: the selection of the optimum (from the point of view of a number of given attributes) way of synthesising some chemical, for instance one which has not yet been mentioned in chemical papers. Following a single algorythm for this class of problems which boils down to the repeated recurrence of a number of elementary operations with the structural formulas, the machine can construct a number of reaction chains which will lead to a desired compound. The machine, as a matter of fact, will model the process of mental activity of a chemist when he compares various types of conversions known to him with some given structure, in order to establish the ways of obtaining this structure with the help of reactions of the known type. A definite possible initial substance (or a pair) corresponds to each reaction which may result in a desired compound. The machine will compare among one other all possible synthesis chains found in this way and select one or several most plausible ways of synthesis which satisfy the given requirements in the best possible manner.

Naturally the results obtained by the machine (just as are the conclusions arrived at by chemists in the course of their reasoning) will be the most plausible working hypothesis which can be checked by experiment.

The qualitative character of chemical reasoning which can be modelled with the help of a chemical information and logical machine to possess all the qualities inherent in mod-

ern high-speed digital computers, opens up broad possibilities for the solution of various unsolved chemical problems by these "inductive" qualitative methods combined with precise computation methods.

As chemistry computation methods develop, an ever greater number of sub-routines of a purely computer character can be included in the programmes for the solution of various chemical problems. Thus the machine can apply in practice all the achievements in the field of computer technique, which are usually too difficult to grasp for most of the chemists working in other fields. It should be noted in this connection that reasoning concerning spatial deductions usually obtained by examining models can be modelled in the machine purely through computation.

The ability of the machine to "learn" and for "self-education" is an important source for raising the operating efficiency of the chemical information and logical machine. For example, after the machine works out answers as to the ways of synthesis of a compound which was not mentioned in the chemical literature before, we introduce into its memory the results of an experimental check-up of the synthesis patterns suggested by the machine. It will then be able to automatically correct data recorded in its memory concerning the conditions for the utilisation of this or that type of reaction according to some preset programme. It means that the answers to the questions worked out by the machine will gradually become more and more trustworthy. Of great importance for the solution of all information and logic problems concerning chemical reactions is the recording in the machine memory of trustworthy information from scientific papers concerning the kinetics and mechanism of chemical reactions to be then included in the scope of the machine logical operations.

The few examples given above of the problems which can be solved with the help of chemical information and logical machines show that the machine can replace the labour-consuming work of a chemist with literature in the solution of certain important categories of problems. What is more, the machine will tackle the job using to the full the abundant information recorded in its memory, a task no human being can accomplish due to his limited life span. The speed of

information processing and the ability of the machine to memorise a practically unlimited amount of information will serve as the source of tremendous economy in highly qualified mental labour.

As the scope of information recorded by the chemical machine memory extends and its computer and various types of machine memory units are improved, the machine will be capable of tackling an ever wider range of problems. Thus the machine beside its initial reference functions will to an ever greater degree undertake the functions of a conscientious and indefatigable highly skilled adviser.

It is not improbable that in the future the development of the information and logical machines will gradually gain in importance and will radically change the current practice of publishing scientific papers. It is very likely that only the papers containing important summaries and certain types of reviews will be published in book form.

Of especial importance for chemical science is the fact that the machine will record the negative results which are so frequent in chemistry practice and which at present rarely appear in print despite their importance for future work as well as the positive.

Information and logical machines, relieving the scientists of mental work which at present must be described and recorded to an ever greater degree, will provide them with broad opportunities for fruitful and creative research work.

## Processing Statistical and Planning Information

Plans, accounts, summaries, instructions virtually deluge administrations forcing them to steadily increase their staffs at the expense of the valuable engineering and technical personnel diverted from production.

The number of office employees is increasing at a much greater rate than the number of workers. Thus, for instance, according to U.S. statistics the number of workers from 1920 to 1950 increased only by 53% while the number of office employees went up in the same period by 150%. The productivity of labour at plants in the last 100 years has increased approximately fourteen-fold while that of the office workers only by one and a half times.

The following examples go to show the enormous amount of statistical and planning materials being processed.

The annual traffic of planning materials from ministries, departments, etc., amounts to more than 10,000 pages containing nearly half a million indices.

Planning data arriving annually from establishments and construction projects takes up several hundred thousand pages and contains scores of millions indices.

An average of several million various bank operations take place daily at the State Bank and its branches. The amount of computing operations at the State Bank connected with the analysis of the financial accounting of various economic organisations and the drawing up of financial plans is exceptionally great, since it credits and controls over half a million enterprises. The picture is the same for railway transport.

The work of industrial establishments is analysed on the basis of annual accounts which contain the indices requiring a thorough study of the work of an enterprise: fixed and circulating capital, profits, losses, debtor and creditor debts, staff, the number of workers and their categories, output per worker, production cost, power consumption, the number of orders and their character, etc.

As the "content" of a part or element is disclosed in a drawing by sections in various directions, the planning and statistical data is studied along various "sections" (by the Soviet Union, republics, regions, ministries, economic councils, branches of industry, etc.).

The planning of a national economy demands a radical improvement of the work of the planning bodies. They should draw up summary, current and long-term plans, and pool and coordinate the activities of economic councils in carrying out these plans.

Of utmost importance is the study of the requirements of the national economy, the resources and the conditions of development of various regions of the country, the accounting of the achievements of science and technology with a view of ensuring the proportionate development of the national economy, more rational use of the country's resources and the development of the production forces in the state interests. Coordination of the activities of econom-

ic councils and state planning bodies will call for all-round study of economic ties between various regions, establishing trends in the development of these ties and drawing up plans of inter-region deliveries of industrial and agricultural products.

To cope with these extremely complicated tasks which face the country's planning bodies today, these organs should be equipped with modern technical means for obtaining, processing and analysing vast quantities of information concerning the development of branches of industry, of production output, of the presence and location of various resources. When the national economic plan is being drawn up, a great amount of planning calculations have to be compared in a rather limited time in order to select the optimum variant from many possible ones.

At present steps should be taken to develop and strengthen a single centralised system of accounting and statistics, and to set up a ramified network of computing stations. Along with this, the reorganisation of the process of planning of the national economy itself on the basis of high-speed machines brooks no delay.

These machines alone can ensure efficient, timely and correct centralised planning on the basis of objective data concerning the level of development, trends and resources of various regions.

The drawing up of national economic plans will require that the high-speed machines solve problems facing the country's planning bodies by processing the technical and economic information and planning data in the shortest possible time; in some cases even on the same day these problems crop up. They may be as follows:

obtaining variants of the national economic plan and the balance of products on the basis of future plans and the demands received from republics and economic councils;

obtaining variants of the balance of products for any given changes in the consumption rates and of other balance links between various types of production;

obtaining any combinations and variants of extracts from the plans and reports concerning republics, economic councils, industrial centres and certain types of production;

13*

determining the effect of the changes of factors on complex synthetic indices (for example, inter-relations between production cost, lowering of the consumption of materials and growing productivity of labour; the inter-relation between productivity of labour and higher wages, etc.);

calculating the changes in the price levels by production branches and regions with due account of balance-ties and inter-dependence;

obtaining extracts from the approved plans for republics and economic councils;

obtaining any information of national and foreign statistics.

The electronic machines of today are mainly intended for solving mathematical problems, for which a comparatively small capacity high-speed machine memory (1,000-4,000 bits) is quite sufficient. Information and logical machines with large capacity (millions of bits) and long-time, rapid-access and durable memory have to be developed for solving problems dealing with statistics and planning. The machine should enlarge its memory by absorbing new information.

The greater the amount of information the machine accumulates with the passage of years, the more valuable and important the conclusions are which can be obtained by analysing planning and statistical data.

The machines for analysing statistical data must be capable of reproducing rapidly parts of the recorded information by given combinations of names, "sections", indices and by other specific attributes of the material sought.

A machine memory of the new type is capable, in principle, of reproducing information with a very great speed. The reproduction speed of the machine memory can be compared with the reproduction of data from a mass of punched cards and magnetic tapes, just like the speed of a jet plane compared to the speed of a horse. The significance of a high-speed memory of this kind capable of replacing paper archives and reading out various references, computing data, performing rapid calculations on the basis of accurate data stored in the course of many years and finally producing different variants can hardly be over-estimated.

Here is an example of the processing of statistical data

with the help of information and logical machines: industrial equipment is accounted for by periodic registration of metal cutting, forging and pressing, building and other equipment. Special forms list a limited number of properties for each type of equipment. A method of registering data of each individual industrial unit is worked out and each item of equipment is given its own number. Now assume that the number of items is 100,000 and the number of properties of each item is 30 (trademark, year of manufacture, specifications, etc.). Then each unit of information should contain $30\times10=300$ bits. The capacity of the entire machine memory will be $10^5\times300=30$ million bits. It will take the machine a few seconds to examine all the information bits by all combinations of 30 properties taken at random (the machine memory read-out speed being 30,000 bits of information per second).

The range of interrogations can be most varied, for instance, about the machines with certain specifications; about the number of operating forging presses requiring overhaul; about the annual increase of the number of copying machines; about the comparative concentration of forging and pressing equipment in ministries and economic councils, etc.

The machine performs these operations as follows: the interrogation programme contains two types of properties—selection properties and calculation properties.

Suppose we want to know the number of operating forging presses in need of overhaul. The selection properties will be as follows: 1) press designations, denoting pressure developed shape, year of installation, etc.; 2) the need for overhaul. Designations of ministries and economic councils will serve as the calculation properties.

The selection properties are fed into the comparer at which also arrives the information retrieved from the machine memory. Each time the selection and the information properties match, the comparer sends a signal to the adder. The latter calculates the number of information bits which match with the selection properties. The resultant sum is printed on the read-out form.

The processing of various reports of the industrial enterprises is similar to the processing described above.

Information machines will open up broad possibilities for a comprehensive and thorough analysis on the basis of various indices of the work of an enterprise, making it possible to compare the efforts of regions, republics, ministries, and economic councils, as well as the work of certain groups of similar enterprises.

The machine will make it possible to compare the work of various enterprises in republics, regions, and economic councils by the following indices: capital investments, labour productivity, number of workers according to categories, waste, idle time, overtime payments, losses, shop and works expenditures, expenditures for inventions, for training of personnel, cancelled orders, utilisation of premises, exploitation of machines and equipment. The work of one enterprise can be compared with that of another in the same branch of industry as regards the investments in equipment, tools and materials and the resultant rise in productivity, output, losses due to waste and idle time; the machine can also compare the work of identical enterprises having similar indices in equipment, production output and labour productivity but differing in average wages, overhead expenses, various non-productive expenditures and production losses.

Information machines of the new type can be successfully used for processing statistical data in various branches of industry, in medicine, meteorology, geology, for military purposes and in many other fields.

Extensive weather-forecasting and hydrometeorological research work is underway in the Soviet Union. The research workers base their investigations on the observation data collected by the extensive network of meteorological stations all over the Soviet Union. The existing processing technique permits of utilising only a very insignificant part of the incoming data. The urgent problems of weather forecasting cannot be solved without new, more efficient and high-speed means of recording, storing and processing of the data collected in recent years.

A highly illustrative example of such a problem, the solution of which will be of utmost importance for effective weather forecasting, will be the study of inertia features of the weather. The crux of the problem lies in calculating

the probability of weather change from one state to another by processing daily data compared with the data of the previous day.

At present there are more than 3,000 weather stations in the U.S.S.R. Each station conducts 15 different types of observations eight times a day. We can safely assume that on an average there were four such daily observations (comprising 15 types of observations) in the last 15 years. Each observation on an average is denoted by a two digit decimal number (six signs of the binary system).

Under these assumptions the total amount of data will approach nearly $5 \times 10^9$ bits (3,000 stations $\times$ 15 years $\times$ $\times$ 365 days $\times$ 4 observations $\times$ 15 types of observations $\times$ $\times$ 6 signs $= 5 \times 10^9$).

The reproduction speed being 30,000 bits of information per second, it will require about 50 hours to examine the entire bulk of information using only one channel. If we use 100 channels the time will be cut down to 30 minutes. There can be no doubt that the new method will revolutionise weather forecasting and help to arrive at practical and theoretical conclusions highly important for the national economy.

One of the most urgent problems of today is the problem of droughts and their control. To develop control measures all the observation data concerning droughts in the past years should be concentrated in the machine memory.

The recording of all the meteorological and hydrological data is facilitated to a considerable degree by the existing international standardised digital system of recording all data used in all branches of the U.S.S.R. Hydrometeorological Service.

With the data reproduction and retrieval speed of 30,000 addresses per second it will take only a single day to examine all the material with any combination of properties (types of observation) using only one channel. At present the weather-forecasting and aerology data for past years in the Soviet Union alone amounts to hundreds of millions of records.

Considerable experience has been acquired in the last decades in processing information with the help of calculating and analytical machines. Information is recorded on

punched cards; this system of information recording has been developed sufficiently well and it can be considered quite satisfactory that it is adopted in a new processing technique where information and logical machines employing high-speed, large-capacity machine memory are used. Machine language has in the main been developed. The next step is the realisation of the project.

Assume, for example, that the introduction of the punched cards with a capacitive memory instead of a mechanical moving one would give us only one new quality—the immobility of the information carriers, while the read-out speed per card remains the same. Even this new quality alone is very important; it will do away with mechanical sorting in the process of information retrieval.

We shall remind you that in order to select one punched card with the required information the whole lot of them has to be sorted. One sheet of information in the immovable machine memory can be retrieved with great speed without any violation or damage to the information carriers.

It should be noted that long-time memory should be used for storing information which is needed in the course of a long period of time; while information for temporary use should be recorded in the volatile memory on magnetic tapes or discs.

The solution of the important problems of processing statistical and planning data lies therefore in combining all types of machine memory.

* * *

The development and introduction of information machines in practice requires considerable capital investments. However, the higher productivity of mental activity as well as a drastic cut in the quantity of printed matter dealing with nothing but compilations, and the reduction in general of the volume of books and journals through elimination of repetitions and expositions will repay these investments many times.

According to a very conservative estimate, the reduction of printed matter will reduce the volume of scientific information by more than a half. Even only with a view to

future economy we can and must develop the production of technical means required for the creation of information machines.

The new form of information recording developed for "machine reading" will represent a new type of the written language—a "machine written language". It will mean a virtual revolution in the productivity of mental labour.

Let us discuss some of the general problems connected with the designing and utilisation of information machines.

At present, when there are as yet no such machines, intercommunication between specialists in various fields can be represented by cross-links, since each discipline (physics, mathematics, chemistry, biology, geology, engineering, etc.) in certain aspects comes into contact with other disciplines and is closely connected with some of them. If we assume that the number of narrow fields of sciences ($n$) is approximately one thousand, then the number of points of contacts will approach a million ($n^2=10^6$).

We shall remind you that very often most valuable discoveries are made as a result of the mutual influence of varied fields of science. Therefore new fields of science standing at the cross-roads of two old ones (i.e., biophysics, biochemistry, mechano-chemistry, chemical physics) gradually acquire self-importance and gain a foothold as accepted disciplines by themselves.

A basic vocabulary of terms and definitions is being formed in each narrow field. This terminology defines new objects of research and the results of their elaboration and introduction into practice. The basic vocabulary of terms grows very rapidly. In chemistry, for instance, the number of names of chemical compounds has topped the 40,000 figure, i.e., it is many times more than the basic vocabulary of an ordinary person (5,000-10,000 words).

For the scientist to work efficiently at the "cross-roads" of any two fields of science, he must master their language. This is tantamount to studying two foreign languages. That is why people who know well, say, five foreign languages are just as rare as persons well-versed in five or more fields of science.

The introduction of a single **machine information language** common for all (an intermediary language) will greatly

facilitate intercourse between specialists in various branches of science.

The results of work in each branch of science translated into one common machine language will be available for specialists in any field.

However, this language should be adopted for "listeners" and "readers" with different levels of qualification. Roughly the following levels can be introduced:

1) special handbooks;
2) encyclopaedias (higher education);
3) general education.

Each level should have its own limited vocabulary.

When ordering information the qualification level should be indicated. This distribution of information according to levels will be most advantageous for scientific workers.

A question arises: what is the qualitative difference between machine handbooks and conventionally printed encyclopaedias. They both will give answers to any combination of attributes, to the logical chain of attributes (functions "AND-AND", "OR-OR", "IF-THEN NO", etc.) and find links between the notions. But if the machine was already asked some question the answer to it will be taken into consideration and duly used.

The volume of our gray matter is growing but slightly from generation to generation. Scientists, for instance, cannot find visible changes in the human cranium in millenniums.

On the contrary, the internal machine memory starting, for example, from 1,000 million bits can be built up at a rather rapid rate and in about 5 to 10 years will exceed 10 to 15 hundred million bits.

However, it should be remembered that man in addition uses an external memory—**written language.** Although the capacity and shape of a human cranium remained the same, our culture nevertheless progressed rapidly after the external book memory has been added to our internal memory.

Maxim Gorky said illustrating this point: "A book is probably the most intricate and grand marvel of all the marvels created by humanity on its road towards future happiness and might."

Books are the treasure-house of the centuries-old experience of humanity. The volume of this external memory is stupendous. It is equal to $10^{16}$ bits and is far beyond comprehension by the internal memory of one person. If a man puts in two hours of reading for 50 years on end he will perceive less than a millionth of the complete knowledge store.

Moreover, other obstacles just as serious stand between the external book memory and the internal human memory which restrict the effective use of printed matter in the process of mental activity (e.g., different languages, narrow specialisation, etc.).

All this goes to show that the comprehension of the external material by man considerably lags behind the ever growing stock of knowledge stored by humanity. The steady increase of the number of narrow specialists, the division of science and engineering into thousands of self-contained branches with their own dialects cannot but be a serious impediment for humanity on its road to social progress.

By analogy we can call the two principally different forms of storing information in the machine electronic memory the **passive** and **active** processes of "learning".

The passive process of "memorising" the material will differ from the active process in one aspect: its self-contained memory units will be electrically connected to the machine. The contents of textbooks and handbooks on this or that subject, rules and regulations, the results of scientific research, census data, the practical experience of this or that mental worker can be recorded separately outside the machine. New units inserted in the machine make it more experienced.

This process is in a way similar to the **educational process** of a mental worker.

However, he or a student can listen to only one lecture or read only one book or study one handbook at a time, whereas a great number of units can be connected up to the machine memory; units which were prepared simultaneously by the machines, by a vast number of specialists in various fields of knowledge, or which contain the material from various handbooks on chemistry, mathematics, physics, geology, etc.

The process of learning of this kind is not limited by the "narrowness of comprehension" of the human brain.

In other words, the analogy goes to show that the machine can be "taught" by thousands of specialists in various fields, each in its own dialect. However, there should be the one condition that every new notion introduced into the machine is supplied with a definition and an indication of its *link* with other notions.

The process of passive learning can continue as long as the machine operates.

But we have already mentioned that the purpose of this machine is to answer practical questions fed into it by many people.

In the most simple case the answer to the question can fully coincide with a stereotype association recorded in the memory. Let there be $N$ stereotypes in the machine. The logical part of the machine performs mainly operations with associations, semantic links, groups, complexes and systems of notions in order to answer questions which require deduction, i.e., the determination of the unknown relation between two notions on the basis of both their known relations with the third notion.

Here is where the problem of utilisation and the further development of logic for modelling the process of mental activity comes in.

Information for this purpose should first of all undergo formalisation. If, for instance, we express information in the language of predicates, it can be logically processed, i.e., in this case from the premises contained in the memory all possible corollaries can be obtained (the research function) and from the obtained or known corollaries premises can be deduced (the explanatory function).

If we insert in the machine memory the axioms of a certain given theory, logical axioms of a general character and the rules of deduction, corollaries (theorems of theories) can be obtained from these premises by the preset programme.

Further development of mathematical logic, and first and foremost th development of the predicate and the theory of algorythms, is of utmost importance for the solution of these problems. The machine is designed to form answers

to the questions which are not recorded in its memory as stereotypes.

Assume, for example, that each valuable answer to the questions is introduced into the machine memory as new information. The questions and the answers are recorded and included in the machine memory as new information. This will be its active memory.

New associations required for further work will be created in the process of finding answers to the questions; as for instance, the complex association establishing links between cause and effect (cause-effect associations).

Let the machine give answers to several such questions, say 100, a day. Then in a year there will be more than 30,000 stereotypes worked out by the machine itself in the course of its practical activity.

This is a new qualitative trend of the machine since by answering the questions the machine works out new information. It is no longer passive learning but the **active** accumulation of practical experience in active **self-education.**

As the results of its practical activity accumulate in the machine memory, the narrow specialisation of materials when specialisation is passive and has a limited approach to questions and answers, characteristic of many people with their purely department interest and narrow-mindedness, are no longer drawbacks of the machine.

The thing is that questions fed in to the machine will be much like the questions which a specialist in one field puts to a specialist in another field, or in the same field but to a person whose knowledge is more extensive.

Thus an agronomist can be interested in agrochemistry or machinery, an electrician in bio-currents, a physician in physics, chemistry, etc.

Answers formed on the basis of extensive material comprising various fields of knowledge will provide valuable new information and improve the machine's performance. Thousands upon thousands of people will take part in training and enlarging the machine's memory since the advantage of its encyclopaedic knowledge and high speed of operation are unquestionable.

The machine will accumulate new information, passively acquiring it from various specialists and building actively

in the process of its work. Here we can draw an analogy with the way mental workers acquire their experience.

In this connection a few important conclusions can be made. Machine processing of all sorts of papers, reports, accounts, etc., sorting them out according to their significance, and storing the most valuable of them, together with the ability to reproduce and send them rapidly over any communication channel to any distance, will undoubtedly revolutionise mental work. Just as book printing which superceded handwriting was the cornerstone of our modern civilisation, the development of large-capacity information and logical machines will in this sense signify the appearance of a new machine "written language", which will serve as the basis for more productive mental work.

Thinking, as Karl Marx observed, is the spiritual product which is directly interwoven in the material activity and the material intercourse of the people. Today this product is reinforced by new types of large-capacity electronic machines capable of "thinking". It is closely connected with and is part of the process of human thinking, directed at thorough study and the mastering of the nature of the world surrounding us, the process of thinking itself included.

The creation of information and logical machines is of great significance for the progress of human culture. This is a very important and difficult task which scientists and engineers must solve.

## TO THE READER

*The Foreign Languages Publishing House would be glad to have your opinion regarding this book, its translation, design and printing, and to receive any suggestions from you.*

*Please write to 21, Zubovsky Boulevard, Moscow, U.S.S.R.*